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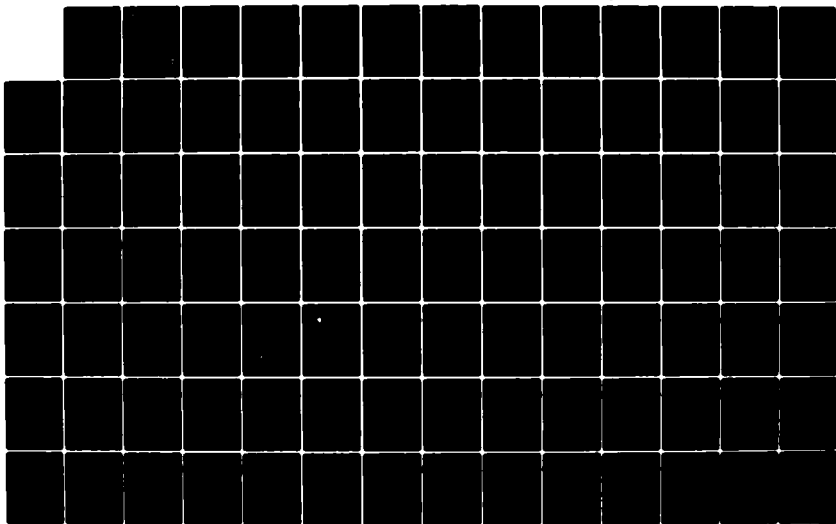
HURRICANE HAVENS HANDBOOK FOR THE NORTH ATLANTIC OCEAN  
CHANGE 1(U) NAVAL ENVIRONMENTAL PREDICTION RESEARCH  
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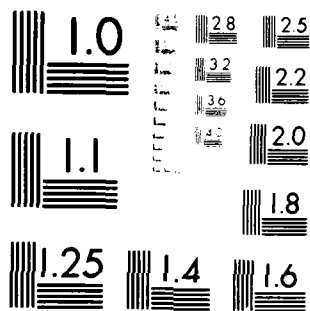
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(b) NAVENVPREDRSCHFAC transmittal sheet 5600 NEPRF/SBB:sb  
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Encl: (1) Change 1 to NAVENVPREDRSCHFAC Technical Report  
82-03, Hurricane Havens Handbook for the North  
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1. The basic volume of NAVENVPREDRSCHFAC TR 82-03, which contains Sections I-XI (less port of Newport, RI, Section IX), was distributed to units of the U.S. Atlantic Fleet by reference (a) and to additional NAVENVPREDRSCHFAC addressees by reference (b).

2. Enclosure (1) is hereby forwarded to all holders of the basic volume as specified in the distributions of references (a) and (b). Instructions for entering these change pages and additional sections into the basic volume are provided as part of enclosure (1).

3. Development of TR 82-03 by this command is a continuing project; distribution of future port evaluations and/or other changes will be made automatically to all holders of the publication.

*Kenneth L. Van Sickle*  
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CHIEF OF DIVISION  
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Page Number/Section:	Action:
DD 1473 of Change 1	Replace DD 1473 originally provided
Pp iii, iv of Change 1	Replace p iii originally provided
P vii of Change 1	Replace p vii originally provided
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This handbook is a ready-reference decision-making aid for commanding officers and other personnel responsible for the safety of ships facing a hurricane threat. Guidance on assessing a hurricane threat and choosing appropriate countermeasures at specific North Atlantic ports is provided in the port evaluations in Sections II-onward. The handbook is not directed exclusively to ships at these ports, however, and the general guidance in Section I will assist ships at other ports or at sea.		

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- (3) Additional port evaluations, Sections XII-XVII, published and distributed as Change One June 1983.

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# INTRODUCTION

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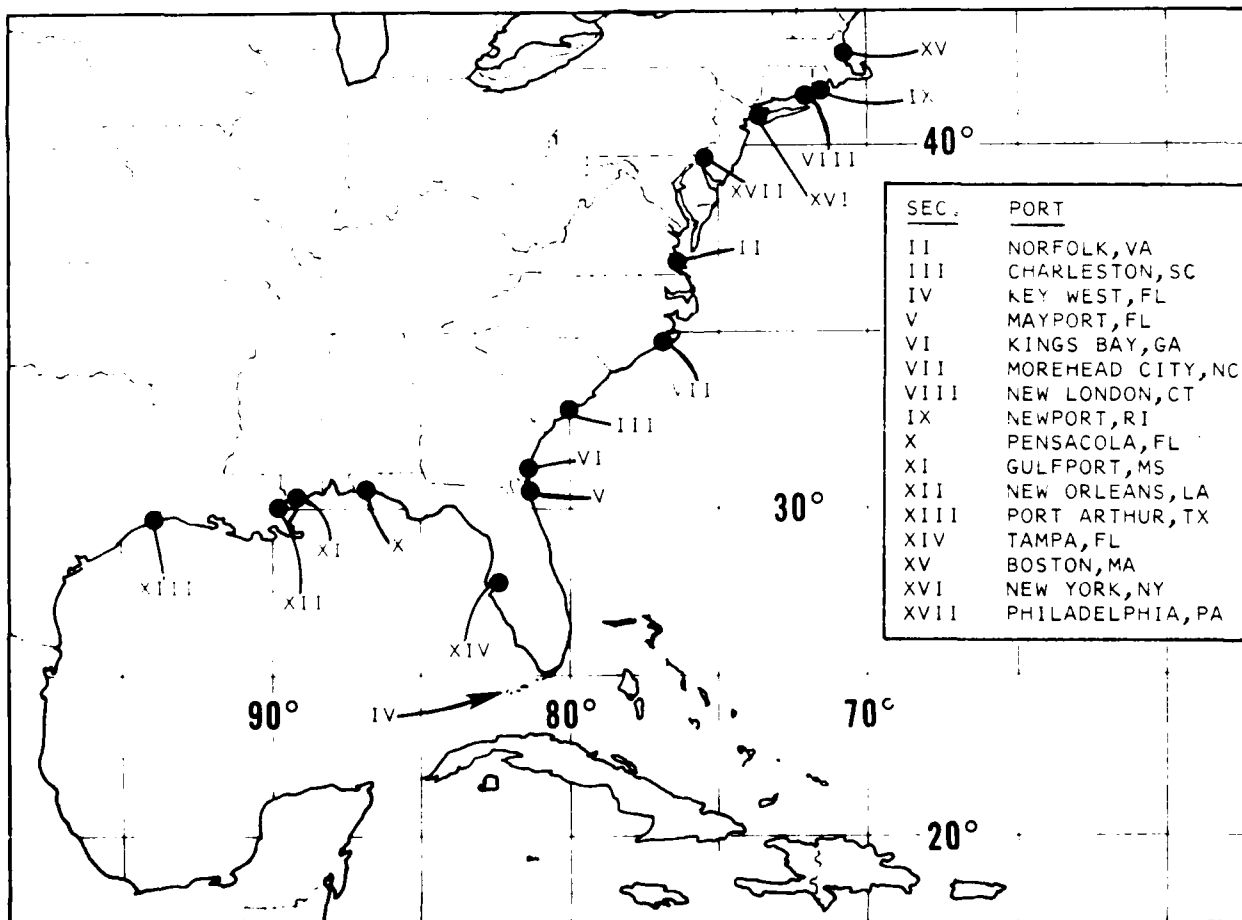
None of the deep-water harbors evaluated in Sections II-XVII possess the exceptional qualities needed to safeguard ocean-going vessels from damage in a "worst-case" direct hurricane strike.

The impact of a hurricane strike at a particular port varies widely and can, to some degree, be forecast according to the particular threat's circumstances.

This handbook provides guidance on assessing a particular hurricane threat in such a way that a reasonable choice can be made between two options -- remaining in port or putting to sea -- with this decision based on a reasoned compromise between a harbor's protective qualities and unnecessary, wasteful sorties.

This handbook is not dedicated exclusively to vessels located at the ports evaluated as hurricane havens in Sections II-XVII. The general guidance provided in Section I will be of value in the decision-making processes aboard ships threatened by hurricanes at other non-evaluated ports or at sea in the North Atlantic Ocean and Gulf of Mexico.

Locations of evaluated ports are shown in the figure below. Roman numerals on the locator map correspond to the numerals designating handbook sections/ports.



Ports evaluated in Sections II-XVII.

XII. NEW ORLEANS, LA



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## XII. NEW ORLEANS, LOUISIANA

### SUMMARY

New Orleans' location in the hurricane belt, and the absence of sheltered facilities and anchorages, render it a poor hurricane haven. It is recommended that deep draft vessels evade at sea when New Orleans is threatened by hurricane force winds (greater than 63 kt). Early threat assessment is absolutely essential due to the distance that must be traveled to reach open water (as much as 135 miles) and to the limited number of evasion routes in the Gulf of Mexico.

Advice to small craft is to remove from the water. Otherwise, seeking shelter in the Pearl River on the Louisiana-Mississippi border is recommended. Little shelter from wind or tidal surge is available at the Port of New Orleans.

New Orleans is the largest port in the United States and the third largest in the world. It is an extremely busy shipping terminal that handles vessels with drafts to 40 ft as well as a multitude of smaller vessels engaged in a variety of marine transportation and service activities. River barge traffic is particularly evident as New Orleans is the southern terminus of the Mississippi River navigation system.

History has demonstrated that the hurricane season poses a real and serious threat to marine activities at New Orleans. New Orleans has been affected by tropical cyclone activity at an average frequency of 1.2 events per year. One out of 7 tropical storms/hurricanes passing within 180 n mi of New Orleans has caused sustained winds greater than 33 kt in the New Orleans area. One out of 15 tropical storms/hurricanes has caused winds gusting to hurricane force (64 kt or greater).

The hurricane season extends from late May through early November, with September being the major threat month. The principal threat to New Orleans is from tropical cyclones approaching from the southeast, south, or southwest. Eighty percent of all tropical cyclones entering the 180 n mi critical area in the 109 year period of 1871 through 1979 approached from these directions.

---

This hurricane haven evaluation was prepared by  
R.D. Gilmore - Ocean Data Systems, Inc. (ODSI),  
Monterey, CA 940.

## NEW ORLEANS, LA

### 1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

As shown in Figures XII-1 and XII-2, the Port of New Orleans is located on both banks of the Mississippi River in the southeast section of Louisiana. The lower and upper limits of the Port are approximately 81 and 115 miles above Head of Passes, a common reference point on the Mississippi River which is located at the junction of Southwest Pass and South Pass, the two main channels leading to the Mississippi River. Head of Passes is 20 miles above the seaward entrance to Southwest Pass (Figure XII-3).

The banks of the Mississippi River comprise the highest terrain in the area, with much of the developed land area along the river actually being below sea level. An elaborate levee system has been constructed by the U.S. Army Corps of Engineers to protect low lying areas from flooding.



Figure XII-1. Mississippi River delta.

## NEW ORLEANS, LA

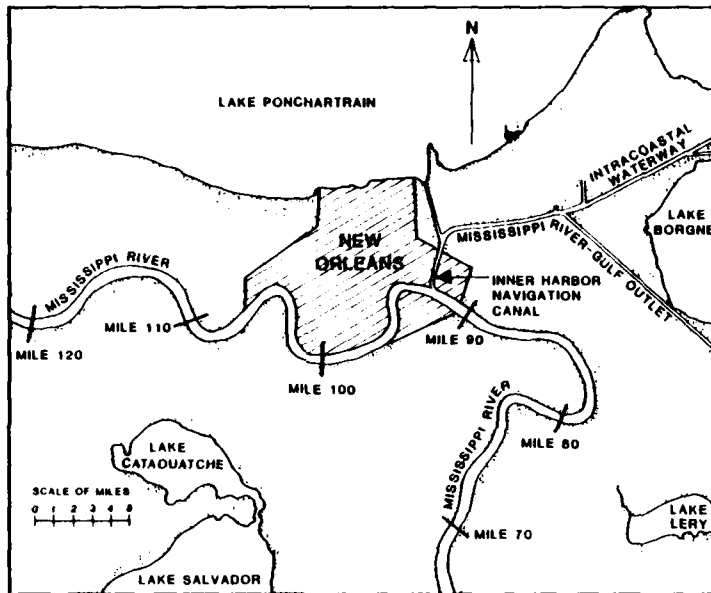
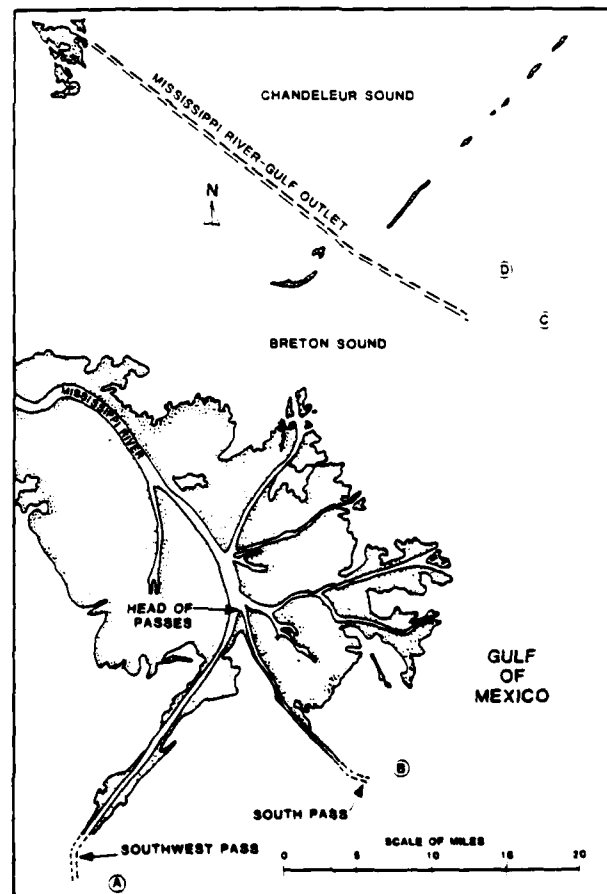


Figure XII-2. Location of New Orleans on Mississippi River.

Figure XII-3. Entrances to Southwest Pass, South Pass, and Mississippi River-Gulf Outlet Canal.



## NEW ORLEANS, LA

The Port of New Orleans can be reached from the Gulf of Mexico by two main routes. The first, and primary, route is via the Mississippi River, which may be accessed by ships using Southwest Pass or South Pass (Figure XII-3). A Federal project provides for a 40-ft channel over the bar and through Southwest Pass, and a 17-ft channel over the bar and through South Pass, to Head of Passes. The project further provides for a 40-ft channel from Head of Passes to New Orleans (U.S. Department of Commerce, 1980).<sup>1</sup>

A second route to the Port of New Orleans is via the Mississippi River-Gulf Outlet Canal (Figure XII-3), a 66-mile channel that extends northwest from deep water in the Gulf of Mexico to the Inner Harbor Navigation Canal at New Orleans. The Federal project provides for channel depths ranging from 36 to 38 ft. Final access to the Mississippi River is via a 640-ft lock at New Orleans. Sill depth at the lock is 31.5 ft at low water (U.S. Department of Commerce, 1980).<sup>2</sup>

There are no bridges or cables across the Mississippi River below New Orleans, but two bridges cross the river at New Orleans. A high level fixed highway bridge connecting Algiers and New Orleans, 0.6 mile above Canal Street, has a clearance of 150 ft over a central 750-ft width. The Huey P. Long Bridge, a combined highway and railroad bridge crossing the river 9.6 miles above Canal Street, has a clearance of 135 ft for a channel span width of 500 ft (U.S. Department of Commerce, 1980).

One bridge and two cables cross the Mississippi River-Gulf Outlet Canal below the junction with the Inner Harbor Navigation Canal at New Orleans. The Paris Road Bridge, a fixed bridge with a clearance of 135 ft, is located about 4.3 miles east of the junction with the Inner Harbor Navigation Canal. The overhead power cables across the canal near the Paris Road Bridge have a clearance of 170 ft (U.S. Department of Commerce, 1980).

## 2. PORT AND HARBOR FACILITIES

### 2.1 BERTHS FOR DEEP DRAFT VESSELS

The Port of New Orleans has more than 180 piers and wharves located on both sides of the Mississippi River, the Inner Harbor Navigation Canal, and the Mississippi River-Gulf Outlet Canal. In addition, over 100 additional facilities for small vessels and barges are located on adjacent waterways. Approximately one-half of the deep-draft facilities are for public use and operated by the Board of Commissioners of the Port of New Orleans. Alongside depths on the Mississippi River facilities generally equal or exceed 30 ft, and deck heights average 22 ft. Some alongside depths and deck heights are less.

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<sup>1</sup>Contact the New Orleans District, Corps of Engineers, for controlling depths.

<sup>2</sup>See Notice to Mariners and latest editions of charts for controlling depths.

## NEW ORLEANS, LA

The primary reason for the unusually high deck heights is the variation in water levels of the river. At New Orleans the extreme difference between high and low stages of the river is 20 ft with the mean difference near 14 ft. The average dates of high-river stage and low-river stage occur in April and October respectively. Zero on the Carrollton river gage (near mile 103) is Mean Sea Level (U.S. Department of Commerce, 1980).

Alongside depths and deck heights for facilities on the Inner Harbor Navigation Canal, the Mississippi River-Gulf Outlet Canal, and adjacent waterways have little uniformity. Complete details of berthing facilities at the Port of New Orleans are to be found in Port Series No. 20 published in 1981 by the U.S. Army Corps of Engineers. The publication also provides details of 55 diesel-operated tugs, ranging from 750 to 4,000 horsepower, used for docking and undocking vessels on the Mississippi River.

Facilities at Naval Support Activity, New Orleans are located near mile 92.8 on the river (Figure XII-4) where the Navy maintains a 374-ft pier on the west bank. With a deck height of 20 ft and an alongside depth of 35 ft, the pier is normally occupied by the USS William C. Lawe (DD-763). Several U.S. Navy small craft utilize facilities located on the shore (south) side of the east end of the main pier structure.

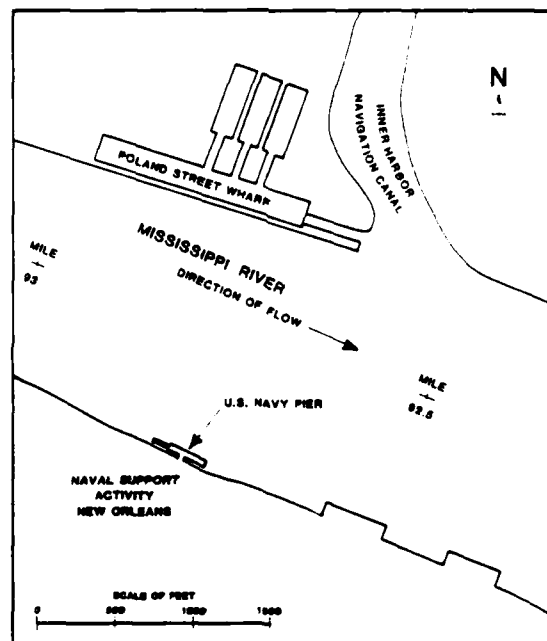


Figure XII-4. Location of U.S. Navy Pier facilities on Mississippi River.

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The U.S. Government also owns and operates the Poland Street Wharf on the east bank of the river opposite the Naval Support Activity pier just described. The Poland Street Wharf has a 2,193-ft face with alongside depths of 32 to 75 ft, and a deck height of 25.5 ft. It is used primarily by the Military Sealift Command, but a section of the pier is leased to a private steamship corporation.

### 2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

The Port of New Orleans offers little shelter from heavy weather. The winding course of the Mississippi River makes some portion of the port vulnerable to wind regardless of direction. The low elevation of the surrounding terrain eliminates any protection that orographic features usually provide, so the only barriers to wind flow are the buildings at or near the piers.

Anchorage for large vessels include the Southwest Pass Anchorage located southeast of the entrance to Southwest Pass, South Pass Anchorage located northeast of the entrance to South Pass, and the Mississippi River-Gulf Outlet Canal Fairway Anchorages located east and north of the Mississippi River-Gulf Outlet Approach Light Horn Buoy. These anchorages are indicated by letters "A" through "D" respectively on Figure XII-3. There is a 4.5 mile long anchorage off the west bank of the Mississippi River opposite Pilottown (1.7 miles above Head of Passes) for vessels which cannot proceed to sea because of fog at the Gulf entrances to the passes, or are unable to proceed upriver for the same or any other reason (U.S. Department of Commerce, 1980).

DMA Map 11368 specifies a quarantine anchorage on the west bank of the Mississippi River at mile 91 above Head of Passes, and a general anchorage at mile 90.

Temporary anchorages may periodically be prescribed between Head of Passes and mile 223 above Head of Passes by the U.S. Coast Guard District Commandant (U.S. Department of Commerce, 1980). Several such anchorages are indicated on the DMA map series for the Mississippi River. Although the river anchorages have mud bottom with generally good holding qualities, none are recommended as heavy weather anchorages due to heavy river traffic and restricted navigation room in the river channel. If heavy weather anchoring is indicated, it should only be considered for heavily ballasted vessels in designated areas on the widest portions of the river.

As specified by Captain of the Port New Orleans Information Bulletin No. 26A, 1 June 1982, and in accordance with Title 33 Code of Federal Regulations (CFR) 165 (Safety Zones), the following areas are designated as Safety Zones upon implementation of Hurricane Condition Four -- hurricane winds possible within 72 hours; vessels are not to be moved or anchored:

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(1) Within the Mississippi River:

Within 500 ft of any water intake.

The forebays or tailbays of all locks.

The lower 400 yards of the New Orleans General Anchorage.

(2) Within the Inner Harbor Navigation Canal:

On both the east and west banks, approximately 100 yards south of Florida Avenue Bridge and 50 ft channelward.

On the West Bank, south of the Seabrook Bridge approximately 200 yards, and 50 ft channelward.

(3) Within Lake Ponchartrain (for commercial marine traffic only)

Tugs are normally used for assisting in docking, undocking, towing in the harbor and canals, and towing to sea. Two tugs must be employed on all towing to and from drydocks and should be employed on all ships towed around Algiers Point when the traffic lights are operating, and by large vessels going through the Inner Harbor Navigation Canal (U.S. Department of Commerce, 1980). Tugs are generally in plentiful supply, but in view of likely increased demand when heavy weather is expected, arrangements for tug services should be made as early as possible.

In the event of damage, complete facilities are available for making repairs to hulls and machinery.

### 2.3 FACILITIES FOR COASTAL AND IN-SHORE VESSELS

The Port of New Orleans is generally free of pleasure boats and commercial fishing boats. Most of these type vessels utilize the docks and marinas located away from the Port area on Lake Ponchartrain, and on numerous small canals and bayous that permeate the entire Mississippi River delta area.

Coastal shipping vessels are accommodated in the Port of New Orleans at the many facilities constructed for that purpose. Docking, bunkering, repairs, food, water, ice and marine supplies are all available.

The Naval Support Activity can provide, or arrange for, all necessary facilities for supporting U.S. Navy vessels visiting or stationed at New Orleans.

## 3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT NEW ORLEANS

### 3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight may be gained into their typical behavior. This background knowledge and understanding allows attention to be focused on those storms most likely to have a serious



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effect on New Orleans. However, the historical behavior of storms and their impact on New Orleans should not be regarded as a reliable guide to the detailed behavior and impact of a particular storm as it approaches the port.

### 3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of New Orleans is considered to represent a threat to the port.

The outstanding feature of the U.S. Gulf Coast region is its location on the north shore of the Gulf of Mexico and its orientation perpendicular to normal tropical cyclone tracks as they move more or less northward out of the tropics. Also of importance is the region's position between 25 and 30 degrees north latitude; this is within the normal locus of tropical cyclone recurvature, which oscillates between latitudes 25N and 35N during the tropical cyclone season. This latter factor is significant since it is the character of tropical cyclones to slow and intensify during the recurvature stage. During this phase of the tropical cyclone life cycle, it is difficult to predict with great accuracy the rate of recurvature, the storm speed of movement subsequent to recurvature, and obviously the storm's precise future position at a point in time.

The hurricane season along the Gulf Coast is late May through early November. During the 109 year period between 1871 and 1979 there were 134 tropical cyclones that met the 180 n mi threat criteria for New Orleans, an average of 1.2 per year. Table XII-1 shows the monthly totals and percentages. These data are graphically presented in Figure XII-5.

Table XII-1. Monthly totals of tropical cyclones passing within 180 n mi of New Orleans during the period 1871-1979.

Month	Number	% of Total
May	2	1.5
June	11	8.2
July	15	11.2
August	24	17.9
September	59	44.1
October	22	16.4
November	1	0.7

Figure XII-6 illustrates 128 events as a function of compass octant from which tropical cyclones have approached New Orleans.\* The numbers in parenthesis represent the percentage of cyclones from the sample approaching from a particular octant. This figure shows that the major threat sector extends from the southeast through the southwest.

\*Some tropical cyclones developed within 180 n mi of New Orleans, so an approach direction is therefore not included for those storms.

# NEW ORLEANS, LA

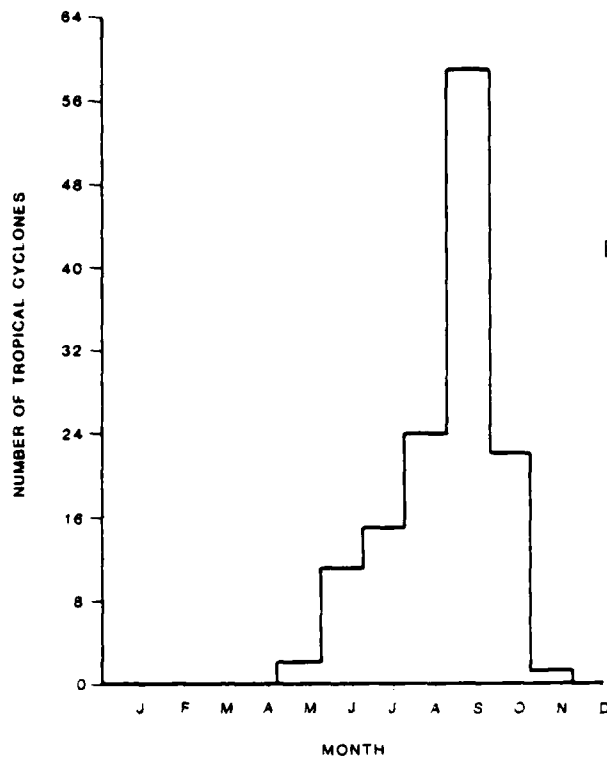
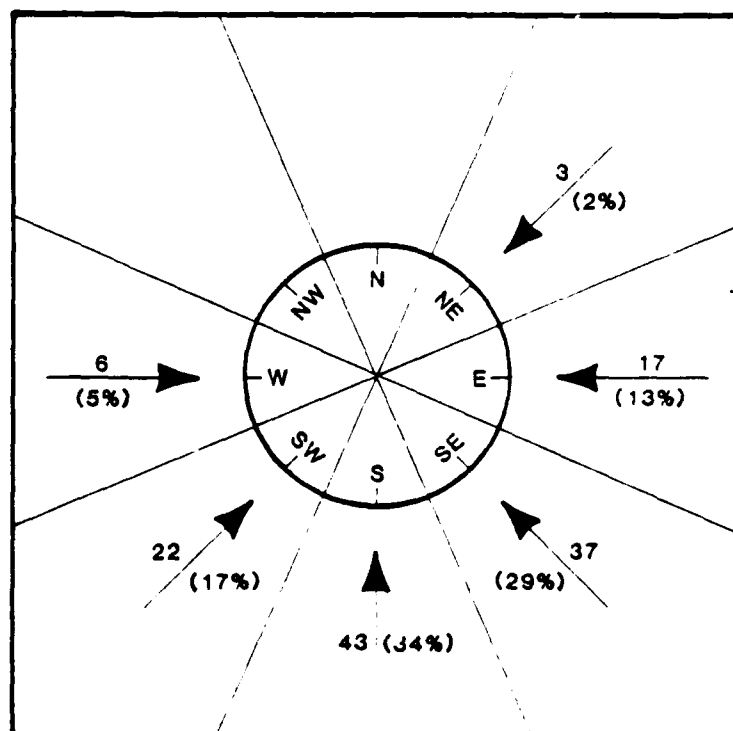


Figure XII-5. Seasonal distribution of tropical cyclones passing within 180 n mi of New Orleans, May-November (based on data from the period 1871-1979).

Figure XII-6. Directions of approach of tropical cyclones that passed within 180 n mi of New Orleans during the period 1871-1979. Numbers of storms approaching from each octant (e.g., 43) and percent of the total approaching from that octant (e.g., 34%) are shown.



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It is significant to note that a small number of tropical cyclones developed within a 180 n mi radius of New Orleans. Three developed quickly into hurricanes while in the threat area.

Records of tropical cyclones passing through the 180 n mi critical area during the 80 year period for which cyclone intensity data are available are tabulated in Table XII-2 by intensity and month of occurrence. Of the 102 such occurrences it can again be seen that September is by far the principal threat month in terms of numbers of tropical cyclones affecting New Orleans. October and November, however, have a slightly higher percentage of the more dangerous classes of storms (12 out of 15). Overall 72 out of 102 tropical cyclones (71%) affecting New Orleans in this century were in the strong (over 47 kt) category.

Table XII-2. Classification of 102 tropical cyclones which passed within 180 n mi of New Orleans during the 1900-1979 period.

Maximum Intensity*	May-June	July	Aug.	Sep.	Oct.-Nov.	Totals
Hurricane	2	3	9	21	5	40
Intense Tropical Storm	5	3	2	15	7	32
Weak Tropical Storm	3	3	5	6	2	19
Tropical Depression	1	3	2	4	1	11
TOTALS	11	12	18	46	15	102

\*Intensity values reflect the maximum intensity while in the final approach phase of the tropical cyclone track. Upper limit of a Weak Tropical Storm is 47 kt.

Figures XII-7 through XII-11 are statistical summaries of threat probability for the years 1871 through 1979. These summary data are presented in five charts, each representing data encompassing specific periods during the year: tropical cyclones occurring during May and June, July and August, September, October and November, and all tropical cyclones of record during the 109-year period.

The solid lines in these figures represent the "Percent Threat" for any storm location. The dashed lines represent approximate approach times to New Orleans based on the climatological approach speed for a particular location. For example, in Figure XII-7, a tropical cyclone located over the northwest corner of the Yucatan Peninsula has a 40% probability of passing within 180 n mi of New Orleans and will reach New Orleans in 72 to 96 hours (3 to 4 days).

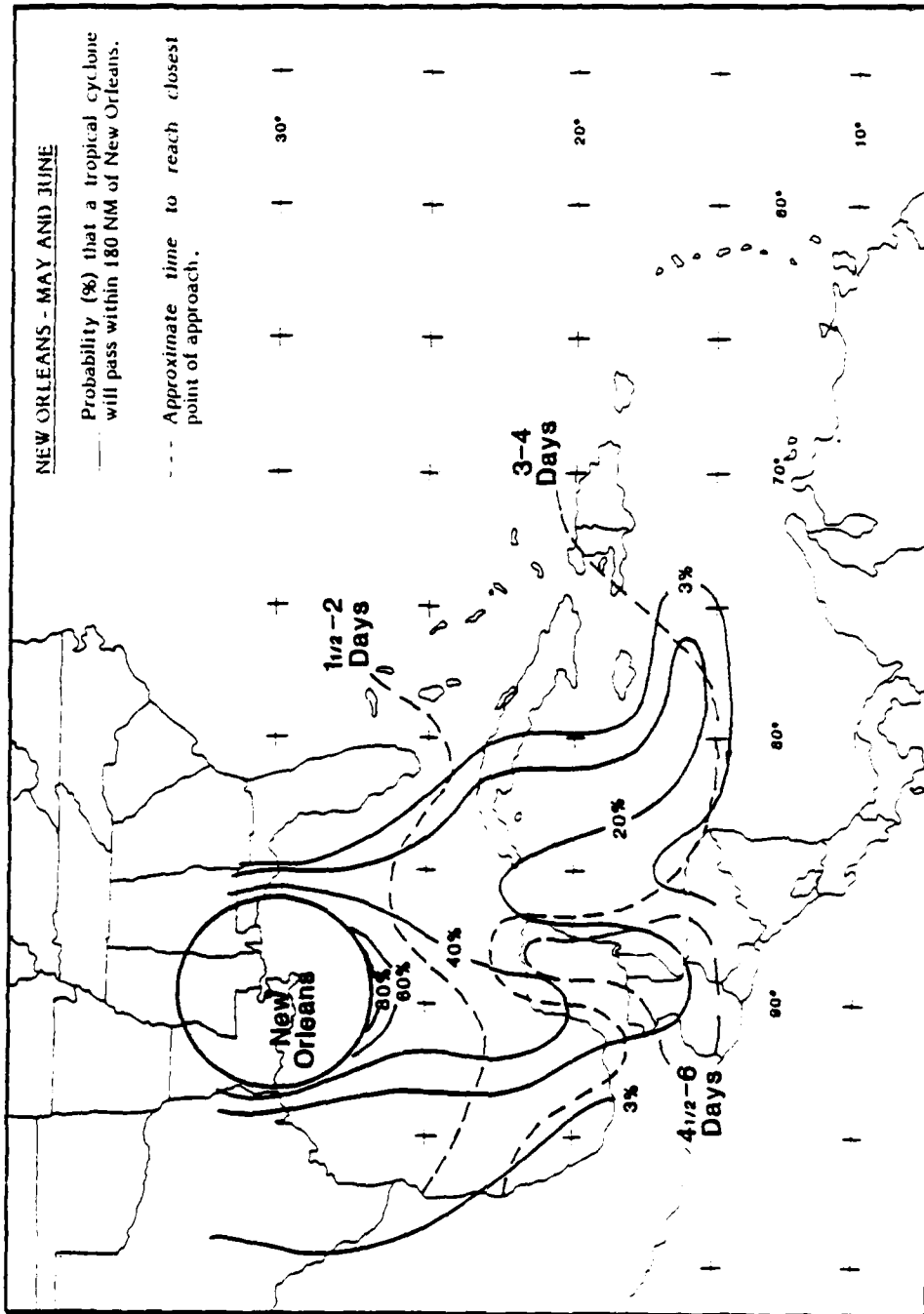


Figure XII-7. Probability that a tropical cyclone will pass within 180 n mi of New Orleans (shaded circle), and approximate time to reach closest point of approach, during May and June (based on data from 1871-1979).

# NEW ORLEANS, LA

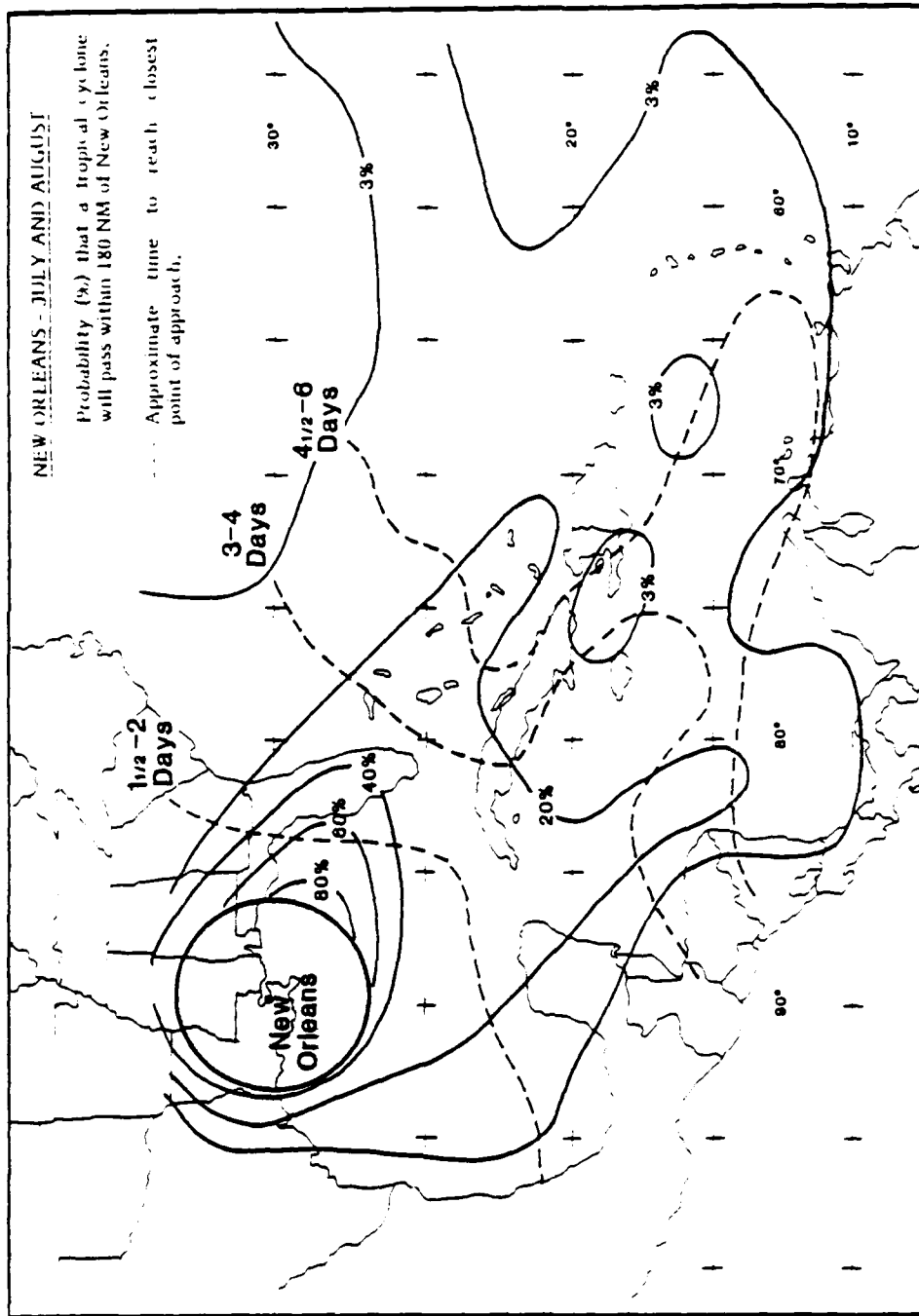


Figure XII-8. Probability that a tropical cyclone will pass within 180 n mi of New Orleans (shaded circle), and approximate time to reach closest point of approach, during July and August (based on data from 1871-1979).

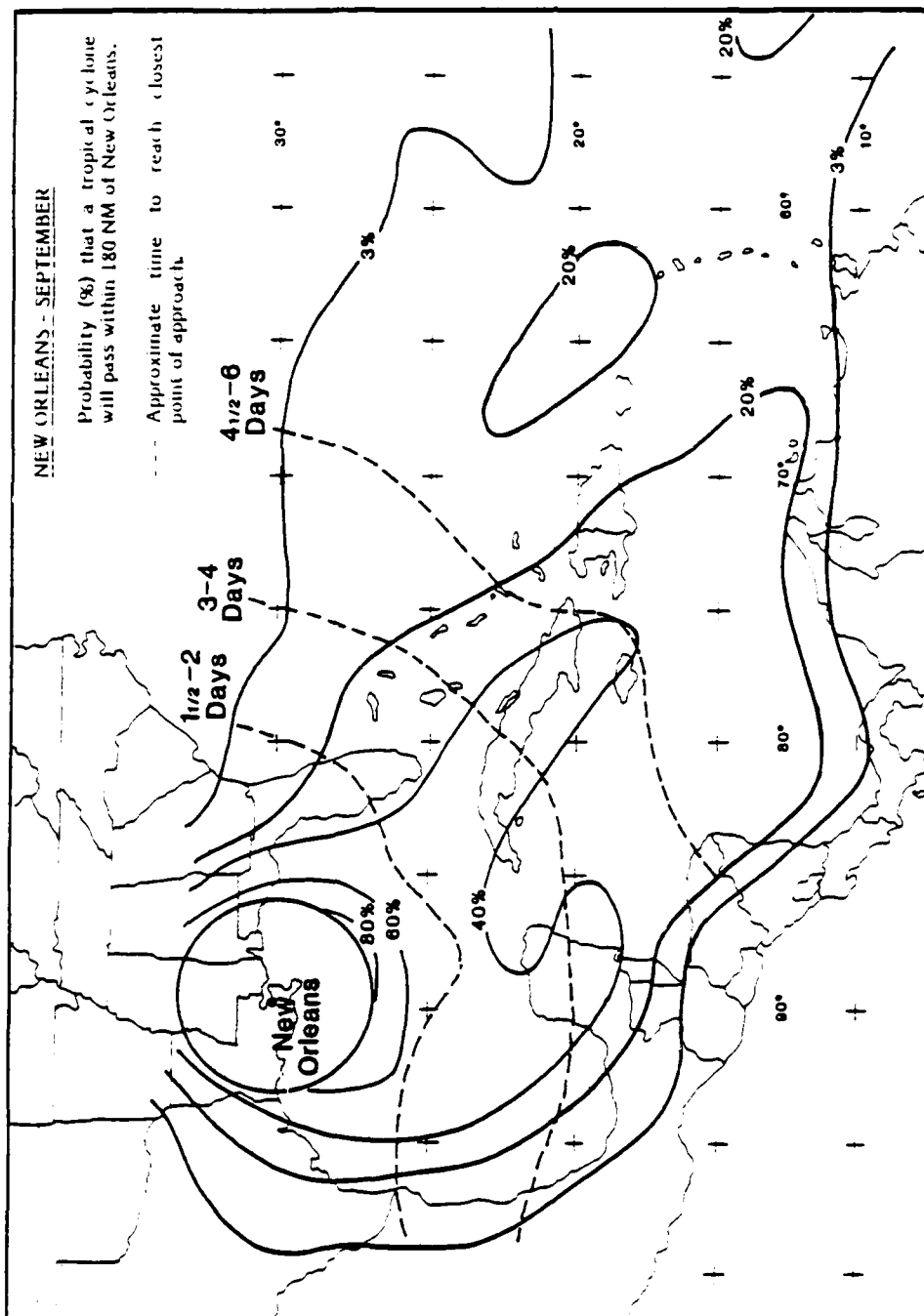


Figure XII-9. Probability that a tropical cyclone will pass within 180 n mi of New Orleans (shaded circle), and approximate time to closest point of approach, during September (based on data from 1871-1979).

# NEW ORLEANS, LA

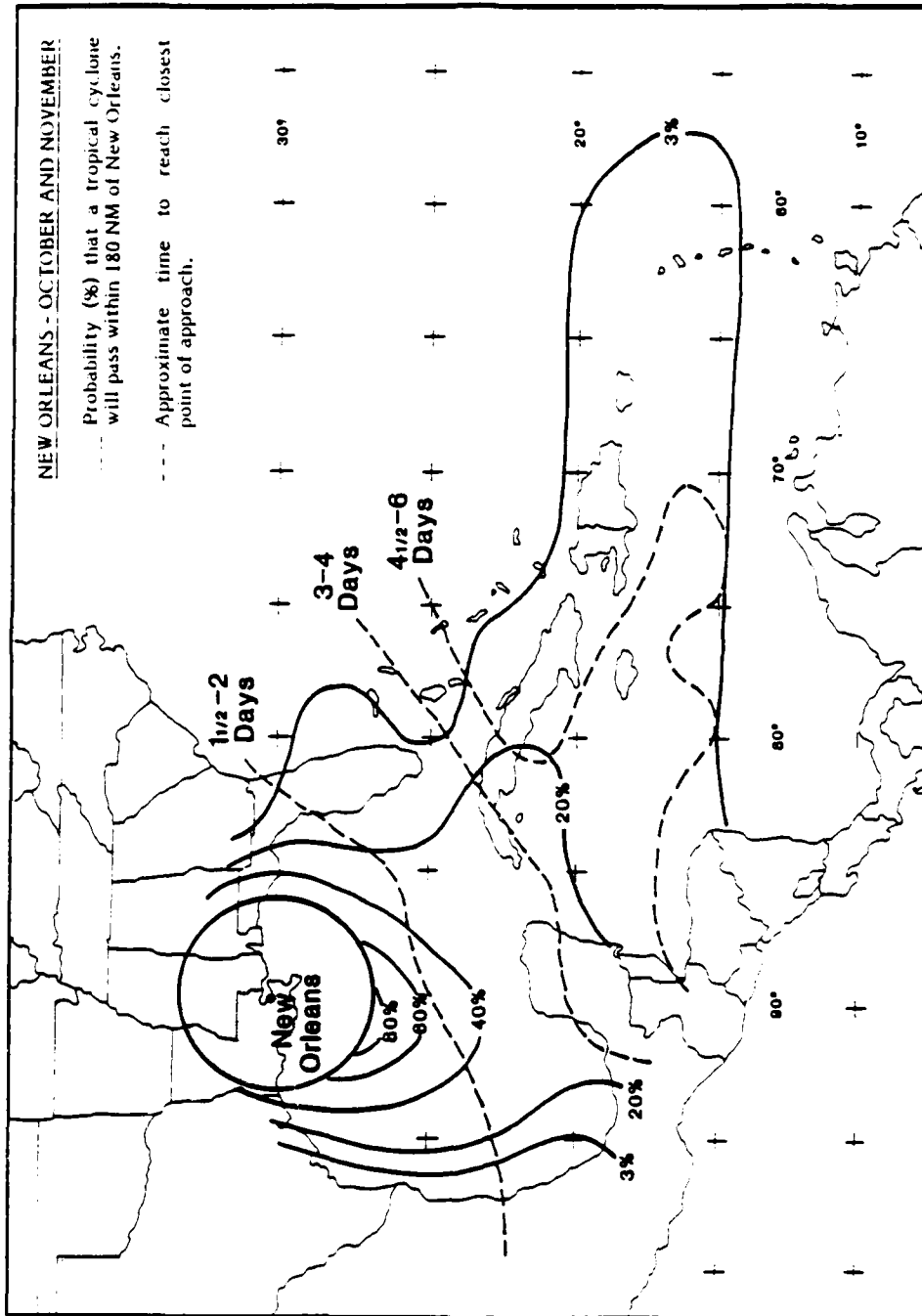


Figure XII-10. Probability that a tropical cyclone will pass within 180 n mi of New Orleans (shaded circle), and approximate time to closest point of approach, during October and November (based on data from 1871-1979).

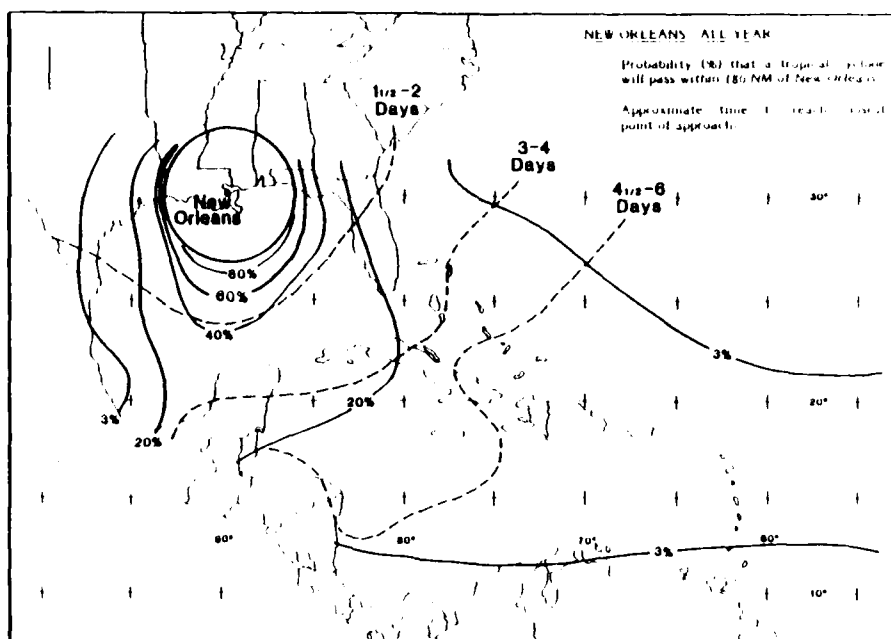


Figure XII-11. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi (shaded circle) of New Orleans, based on data from 1871-1979.

The average speed of advance for all tropical cyclones with winds of at least 34 kt that have threatened New Orleans is 8 kt, with a 7 kt speed evident in June and July increasing to 10 kt during October and November (Neumann and Pryslak, 1981).

A comparison of the figures suggests some distinct differences in threat axis according to time of year. Early in the season (May and June, Figure XII-7) the main threat to New Orleans is a track from just south of Jamaica northwest across the western tip of Cuba to the central Gulf of Mexico then northward to New Orleans. A secondary threat axis extends from the western portion of the Yucatan Peninsula northward to New Orleans.

As the season progresses into July and August (Figure XII-8) the main threat axis shifts northward, following the Bahama Islands northwestward across Florida, thence west-northwestward across the northern Gulf of Mexico to New Orleans. A secondary threat axis is located from the western Caribbean Sea just east of northern Nicaragua north-northwestward through the Yucatan Channel to New Orleans.

In September (Figure XII-9) the main storm threat shifts southward, and extends from the Lesser Antilles northwestward across Cuba and Gulf of Mexico to New Orleans. A secondary threat axis extends northwest from the Yucatan Peninsula to the western Gulf of Mexico thence northeastward to New Orleans.



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The primary threat axis for October and November (Figure XII-10) starts at the north end of the Lesser Antilles and extends westward, passing over the west end of Cuba to the central Gulf of Mexico, recurving northward to New Orleans. A minor threat axis extends across central Florida westward to New Orleans.

Figure XII-11 represents a composite picture of threat probability and time to CPA curves for the entire year and is derived from all tropical cyclone tracks passing within 180 n mi of New Orleans during the period 1871-1979.

### 3.3 WIND AND TOPOGRAPHICAL EFFECTS

Wind data for this evaluation have been extracted primarily from hourly records of the New Orleans Airport Station with supplemental data extracted from hourly records of Naval Air Station, New Orleans. Data from other, more remote, stations were reviewed but were considered to be non-representative of conditions in the port area. A comparison of records for coincident time periods showed that, although the landscape around New Orleans is of generally low elevation, it does reduce wind speeds from that experienced at exposed locations around the periphery of the Mississippi River Delta.

In the 48-year period (1932-1979) for which wind data are available, 68 tropical cyclones approached within 180 n mi of New Orleans, an average of 1.4 per year. A tabular breakdown based on intensity of these cyclones while within the 180 n mi radius is shown in Table XII-3.

Table XII-3. Classification of the 68 tropical cyclones which passed within 180 n mi of New Orleans during the period 1932 through 1979.

<u>Hurricane</u>	<u>Tropical Storm</u>	<u>Tropical Depression</u>	<u>Total (No.)</u>
(>63 kt)	(34 to 63 kt)	(<34 kt)	
24	36	8	68

Of the 60 hurricanes and tropical storms, 9 caused sustained winds greater than 33 kt in the greater New Orleans area, based on hourly wind observations from 1932 through 1979. Three of the 9 caused sustained winds of 50 kt or greater and 4 of the 9 caused gusts reaching hurricane force. Only one storm, the hurricane of September 1947 which passed directly over New Orleans, caused sustained winds of hurricane force. That particular storm originated east of the Cape Verde Islands near the west coast of Africa, and had traveled approximately 4,000 n mi before causing winds of 95 kt with gusts to 109 kt at New Orleans. Based on the 1932 through 1979 wind data, gale force winds can be expected from 1 out of every 7 tropical storms/hurricanes passing within 180 n mi of the port.

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Figures XII-12 through XII-14 display the tracks of all 9 tropical cyclones (Neumann et al., 1978 and Hebert, 1980) that produced sustained winds greater than 33 kt at New Orleans. Three figures are used simply to reduce clutter. Five of the tropical cyclones occurred in September, two in August, and one each in July and October. Also depicted are the tracks of 10 of the more significant storms producing sustained winds of over 22 kt at New Orleans. It is significant to note that 16 of the 19 cyclones approached from a general south or southeasterly direction.

As was mentioned in Section 2.2, the winding course of the Mississippi River makes a portion of the port of New Orleans exposed to the vagaries of the wind regardless of direction. The low elevation of surrounding terrain effectively eliminates orographic barriers, so the buildings at or near the piers provide the only real barriers to wind flow. In general terms, however, the east-west orientation of the river in the most heavily utilized areas of the port renders the port most vulnerable to winds with strong east or west components. The port would be most protected from north or south winds because of the frictional effects of terrain and the protection the buildings along the river could provide.

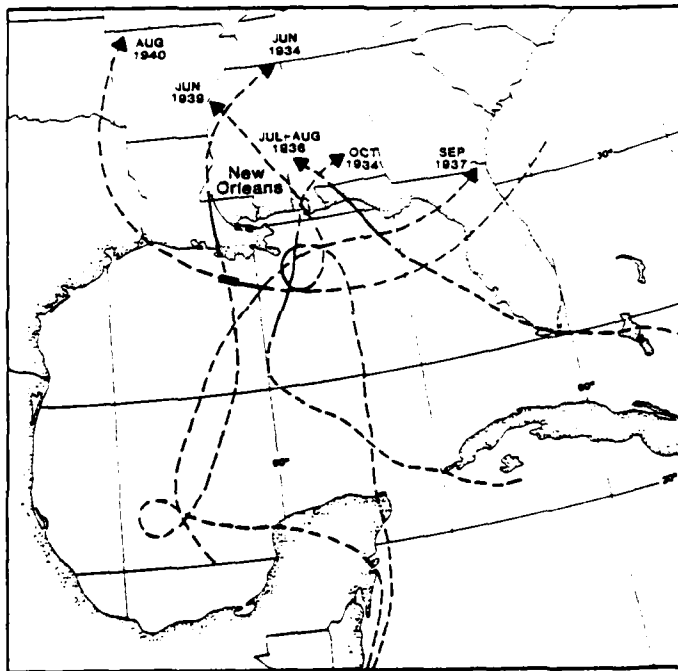


Figure XII-12. Tropical cyclone tracks 1934-40 showing positions of storms when winds greater than 22 kt (thin solid segment) and greater than 33 kt (broad solid segment) occurred at New Orleans, based on hourly wind data.

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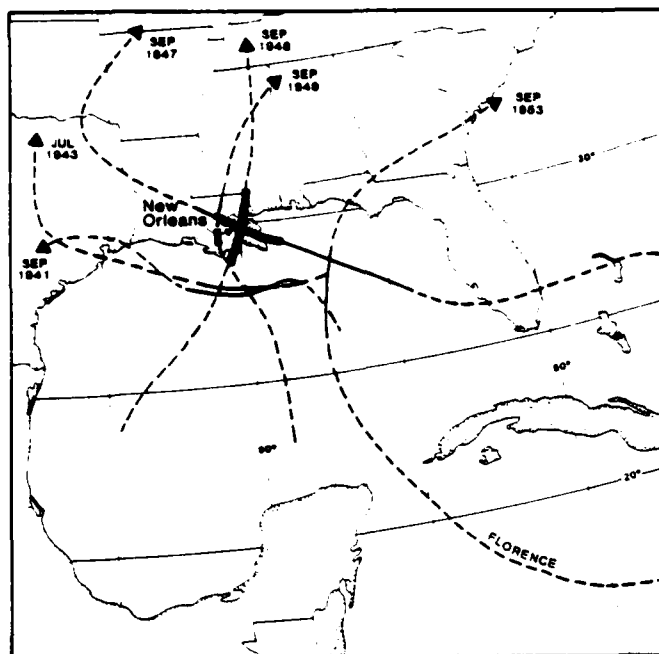


Figure XII-13. Tropical cyclone tracks 1941-53 showing positions of storm centers when winds greater than 22 kt (thin solid segment) and greater than 33 kt (broad solid segment) occurred at New Orleans, based on hourly wind data.

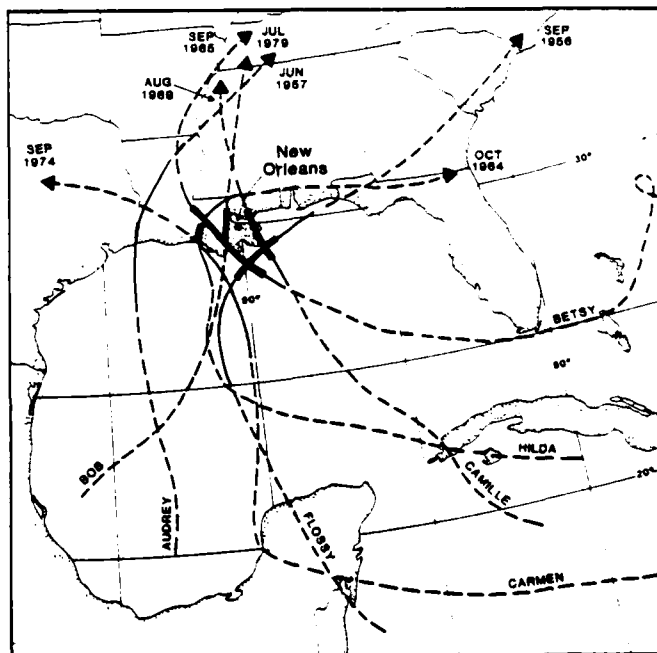


Figure XII-14. Tropical cyclone tracks 1956-79 showing positions of storm centers when winds greater than 22 kt (thin solid segment) and greater than 33 kt (broad solid segment) occurred at New Orleans, based on hourly wind data.

### 3.4 WAVE ACTION ON THE MISSISSIPPI RIVER

Ocean waves are a factor on the Mississippi River only in cases of extremely high tidal surge when the levees are topped or broken. The potential for this occurrence is greatest in the lower reaches of the river and negligible in the port area. Wave action in the port is therefore limited to locally generated wind waves.

The winding course of the river in the port area effectively reduces fetch length to no more than approximately 8 miles. If channel depth of 40 ft and tidal surge heights of 10 ft are assumed, giving a water depth of 50 ft, the maximum waves generated by an 85 kt wind in the port area of the Mississippi River would be about 10.3 ft with a period of 6.3 seconds. Given the same water depth and fetch length, calculations indicate a sustained wind of 25 kt can generate 2.9 ft wind waves; 35 kt winds, 4.3 ft wind waves; 50 kt winds, 6 ft wind waves; and 75 kt winds, 9 ft wind waves (U.S. Army Corps of Engineers, 1973).

At a more realistic fetch length of 5 miles, the wind wave heights are reduced by about 10-15 percent. Eliminating tidal surge and basing calculations on a 40 ft water depth has little effect on the result with wind wave heights remaining essentially the same until the wind speed exceeds 75 kt. Maximum wave heights for an 85 kt wind are then reduced to about 9.5 ft.

It should be noted that the preceding calculations are based on a uniform depth over an assumed relatively flat bottom. Uniform depths are not realistic in the Mississippi River, as the channel is invariably deeper than the river bottom adjacent to it, and the channel depth varies greatly from one location to another -- as deep as 192 ft in one location in the port area. Consequently, the calculated values given above are for use as a guide only and should not be regarded as absolute values.

### 3.5 STORM SURGE AND TIDES

Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles to the right of its path. This dome height is related to local pressure (i.e., a barometer effect dependent on the intensity of the storm) and to local winds. Other significant contributing factors are storm speed, direction of approach, bottom topography, and coincidence with the astronomical tide. The worst circumstances (Harris, 1963) would include the following:

- (1) Intense storm approaching perpendicular to the coast with landfall within 30 n mi to the west.
- (2) Broad, shallow, slowly shoaling bathymetry.
- (3) Coincidence with high astronomical tide.

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The coastal waters surrounding the Mississippi River delta fulfill these criteria during hurricane season.

Two instances of storm surge that caused extensive flooding to the Mississippi River delta occurred during September. Hurricane Carmen, a 150 mph storm, occurred in September 1974, and, although severe flooding was experienced in several outlying parishes, water rises caused by Carmen caused little flood damage in the Port of New Orleans. Tidal surge increased water levels along the coast at Terrebonne Parish (some 60 miles southwest of New Orleans) to 11.64 ft MSL, nearly 10 ft above normal. Water rises in the Mississippi River were limited to 3 to 4 ft in its lower reaches, so the Port of New Orleans was not adversely affected (U.S. Army Corps of Engineers, 1975).

Hurricane Betsy, which occurred in September 1965 was another story, however. Betsy followed what is essentially a "worst case track," moving inland just west of the mouth of the Mississippi River on a northwesterly course. This track brought the brunt of the 125 mph winds along the length of the river to New Orleans, and into the relatively shallow waters of Lake Borgne, Lake Ponchartrain, Breton Sound, Chandeleur Sound, and Mississippi Sound. Except for Orleans Parish and Jefferson Parish, most of the Mississippi River Delta was inundated by flood waters. Although not as strong as Carmen, Betsy played havoc with interests along the Mississippi River from the Port of New Orleans southward. Tidal surge increased water levels on the Mississippi River to 12.61 ft above MSL at Chalmette (near mile 88), 15.25 ft above MSL at West Pointe a la Hache (near mile 49), and 6.57 ft above MSL at Head of Passes (U.S. Army Corps of Engineers, 1965).

A new storm surge forecast model has been developed by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service. It is referred to as SLOSH and estimates the Sea, Lake, and Overland Surges from Hurricanes (Jelesnianski and Chen, 1979) as discussed by Schexnayder and Barnes (1980) and Crawford (1979). Values have been computed for the New Orleans area using a SLOSH model with a 4 n mi grid. Eighteen storm tracks were evaluated, comprising six directions of travel, with three parallel tracks for each direction. Three storm intensities were chosen, with the weakest having a central pressure of 970 mb. The medium strength storm corresponded to about 940 mb, similar to Hurricane Betsy in 1965. The strongest one, a 910 mb storm, is similar to Hurricane Camille in 1969 (Schexnayder and Barnes, 1980).

In general, storms from the southeast were calculated to bring the most severe flooding to the Mississippi River delta. Selected points with corresponding maximum calculated surge values for a 910 mb storm moving from southeast to northwest and tracking over the Mississippi delta just west of the Mississippi River are given in Table XII-4 (New Orleans Area Weather Service Forecast Office, 1980).

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Table XII-4. SLOSH model surge height calculations for points along Mississippi River from Head of Passes to above New Orleans.

Location	Surge Height (Above MSL)
Head of Passes (Mile 0)	11.2 ft
Buras (Mile 25)	15.3 ft
Port Sulphur (Mile 39)	17.3 ft
Violet (Mile 84)	23.9 ft
New Orleans (Mile 95)	17.5 ft
Bonnet Carre Pt. (Mile 133)	10.1 ft

Tidal surges reaching the calculated values would inundate almost all of the Mississippi River delta except for land areas protected by the levee system in and near New Orleans.

Storms approaching from directions other than southeast can also cause severe flooding due to the exposed location of the Mississippi River delta and the extremely low elevations of the land areas.

Astronomical tides at the entrance to Southwest Pass are diurnal with a range of 0.9 to 1.4 ft. No tide is felt at New Orleans during high river stages, but the tidal range averages about 0.8 ft at low river stages (U.S. Department of Commerce, 1980).

River currents are largely dependent on the stage of the river. At New Orleans, the cross-sectional velocity may be as much as 5 kt at high stages and less than 1 kt at low stages. Tidal currents in the river are not strong at any point (U.S. Department of Commerce, 1980).

#### 4. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for hurricane preparedness at Naval Support Activity, New Orleans are addressed in Commandant, Eighth Naval District and Area Coordinator, Eighth Naval District Disaster Preparedness Plan, 1980. Naval Air Station, New Orleans is governed by COMTRAWING Six Instruction 3140.10. The Captain of the Port of New Orleans promulgates a Hurricane Readiness Plan that addresses standard procedures for hurricane readiness for the U.S. Coast Guard. Definitions of conditions of alert are presented together with status of preparedness and action required or recommended to attain each condition of readiness.

##### 4.1 THREAT ASSESSMENT

For the masters of deep draft vessels at the Port of New Orleans, the lack of protected berths coupled with the elapsed time to negotiate the Mississippi River or Mississippi River-Gulf Outlet Canal to open water in the Gulf of Mexico

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make early assessment of each tropical cyclone threat absolutely essential. This assessment should be related to the setting of hurricane conditions of readiness by U.S. Navy, U.S. Coast Guard, and civil authorities and conducted using current advisories and forecasts issued by the Navy and National Weather Service, as well as climatology as presented herein.

The greatest threat to New Orleans in terms of severity is tropical cyclones that have an origin outside the Gulf of Mexico and approach from the southwest, south, or southeast with a forecast landfall within 100 n mi of the port. A greater threat of storm surge occurs when tropical cyclones approach more or less perpendicular to the coast and make landfall within 100 n mi west and 75 n mi east of New Orleans. Of course the individual storm intensity and speed of movement affect the extent of damage which can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that New Orleans is located in the dangerous right front quadrant of the storm can result in severe wind and storm surge conditions. The months of maximum threat in terms of frequency and severity are August, September, and October. All four of the tropical cyclones that caused sustained winds or gusts to hurricane force at New Orleans occurred in September.

### 4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy deep draft vessels when the port is under threat from a hurricane (winds greater than 63 kt) approaching from the Gulf of Mexico and forecast to pass within 100 n mi of the Port of New Orleans. Timing of this decision is affected by:

- (1) The forward speed of the tropical cyclone.
- (2) The radius of hazardous winds and seas that can impact on a vessel's capability to reach open water and then maneuver to evade.
- (3) The elapsed time to make preparation to get underway.
- (4) The elapsed time to reach open water.

For example:

The worst case situation would be an intense cyclone moving more or less directly toward New Orleans from the southeast. Assume 6 hours are required to make preparations for leaving port after the decision to evade at sea is made. Approximately 8 hours are required to transit the Mississippi River and reach open sea, and once open sea is reached, the vessel would be approximately 80 miles further south and closer to the storm. A tropical cyclone approaching at an average speed of 10 kt will have moved 140 miles closer to New Orleans by the time open water is reached. Add to this the radius from the tropical cyclone center of strong winds likely to hamper port operations, say 200 n mi. Summing these values gives 420 miles (140 + 80 + 200) or 42 hours as the minimum

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tropical cyclone displacement from New Orleans in distance or time when the decision must be made to evade at sea successfully. A greater margin may be applicable depending on greater cyclone speed and intensity, and ship speed capability.

Hurricane Condition III is set when hurricane force winds are possible within 48 hours. It is apparent that the decision to prepare for sortie should be made soon after setting Hurricane Condition III. Although at this time the storm may be more than 500 miles distant, it should be remembered that the average tropical cyclone forecast error over a 48 hour period is on the order of 220 n mi for those tropical cyclones threatening New Orleans.

The destroyer USS William C. Lawe (DD-763) is homeported at New Orleans and makes for open sea whenever Hurricane Condition of Readiness III (hurricane force winds expected within 48 hours) is set. This is considered to be the wise and safest course of action. Later departures than this wager the accuracy of information on the storm's behavior against mounting risks of heavy weather damage.

Once sea room is attained on departure from New Orleans, the tactics employed will depend, of course, on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement. Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information with today's satellite technology is accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity, and movement.

Ship masters with access to these advisories/warnings are in the best possible position to modify evasion routes and tactics to successfully evade the storm. The cardinal rule of seamanship is to avoid the dangerous right-hand semicircle. The following guidelines are offered.

(1) For tropical cyclones approaching from the east or southeast: Steam southwest to increase distance from the storm taking advantage of northerly winds and seas.

(2) For tropical cyclones approaching from the southwest or west: After an early departure to escape worst effects of head winds and seas, steam south or south-southeast to reach a latitude south of the storm center.

(3) For tropical cyclones approaching from the south: Tropical cyclones moving through the Gulf of Mexico from this octant present the most vexing of evasion problems. Early in the season many storms move directly into the coast, but in September and October there is a strong likelihood of cyclone recurvature to the northeast while still centered over the Gulf. An evasion route decided on earlier may have to be altered based on unexpected changes in cyclone movement. Evasion tactics must be based on the latest tropical cyclone forecast position and movement.



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### 4.3 RETURNING TO PORT

The damage and disarray at a port resulting from a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Because the Port of New Orleans can only be accessed by long, narrow channels such as the Mississippi River and Mississippi River-Gulf Outlet Canal, the potential for such hazards is large. Harbor facilities may be so damaged as to preclude offering even minimal services. Check with the Port Authority before attempting to return.

### 4.4 REMAINING AT NEW ORLEANS

Remaining in port at New Orleans is an option that should receive serious consideration only in a secondary threat situation or in those instances when a vessel is incapable of successful evasion at sea. The secondary threat situation includes:

- (1) A tropical cyclone developing within the 180 n mi radius critical area.
- (2) A weak tropical cyclone (maximum winds less than 48 kt) is approaching from the Gulf of Mexico, and is forecast not to intensify.
- (3) A tropical cyclone with winds greater than 47 kt approaching from the Gulf is forecast to pass more than 100 miles from New Orleans and the forecast 50-kt wind radius does not encompass the Port of New Orleans.
- (4) A tropical cyclone, approaching overland from the east or west.

If the decision is to remain in port at New Orleans, the following recommendations are offered:

- (1) If the vessel is of a type that cannot easily be ballasted down to maximum draft, such as a man-of-war or cargo ship, remain at the pier secured with sufficient lines to withstand hurricane force winds, yet allow for water height fluctuations of the predicted surge amounts. Bow and stern "insurance lines" of heavy wire rope are recommended.
- (2) If the vessel is a tanker type that can be ballasted down to maximum draft, it can go to anchor utilizing two anchors with 6 shots of chain. The vessel should then be ballasted down to maximum draft, resting on the mud bottom of the river if possible.
- (3) A third possibility is to proceed upriver to Baton Rouge. Channel depths of 40 ft are maintained to Baton Rouge, and because it is further from the Gulf of Mexico, winds are likely to be weaker and hurricane surge heights will be reduced if not eliminated. Baton Rouge facilities are limited, however, and river barge traffic is much heavier than at New Orleans. Consequently, congestion is likely and the threat of waterborne hazards due to broken moorings, etc., is greater.

## NEW ORLEANS, LA

Should a master choose to remain in port, it should be borne in mind that his vessel will be exposed to dangers beyond that of wind and surge. Invariably, many barges and other vessels are broken loose from their moorings on the river and become floating hazards, resulting in holings of some hulls. Also, because the channels from the Port of New Orleans to the open sea are relatively narrow, the risk is considerable that one or both of the channels could be blocked by damaged or sunken vessels, thereby trapping shipping in the port for some time after a storm has passed.

### 5. ADVICE TO SHALLOW DRAFT VESSELS

Shallow draft vessels should, if feasible, be removed from the water and firmly secured ashore at an elevation of at least 20 ft to avoid possible high water. For those vessels that cannot be removed from the water, few options remain. The Mississippi River offers little protection. Tug boats and other similar vessels usually seek shelter in Chalmette Slip (near mile 90.5 on the east bank), and in Harvey Canal (near mile 98.3 on the west bank). Space in these waterways is limited so early access is recommended if their use is desired.

The Naval Support Activity removes as many of its small craft from the water as can be accommodated by its pierside crane. The remaining vessels are sent via the Intra-coastal Waterway to the Pearl River, on the border between Louisiana and Mississippi, where they seek shelter upriver near Pearlington. This alternative requires in excess of 6 hours, and because small craft are involved, must be completed before the onset of heavy weather.

Riding out a tropical cyclone on the Mississippi River is not recommended. Although the twisting course of the river largely precludes wave action of significance to larger vessels, wind driven waves to 10 ft are possible in some areas of the river and smaller vessels could be severely damaged or sunk. Additional hazards are posed by floating debris resulting from the effects of waves, high water, and strong winds.

The prudent small boat operator will have selected several potential havens beforehand in which to take shelter in various tropical cyclone threat situations. He will proceed to his haven well in advance to avoid the chaos and congestion endured by other 'skippers who delay until the onset of destructive conditions is imminent.

## NEW ORLEANS, LA

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XIII. PORT ARTHUR, TX

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2. Port and Harbor Facilities . . . . .	XIII-4
3. Analysis of the Tropical Cyclone Threat at Port Arthur . . . . .	XIII-9
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### XIII. PORT ARTHUR, TEXAS

#### SUMMARY

While each port has specific advantages, none of the ports of Port Arthur, Beaumont, or Orange has the qualities required of a good hurricane haven. Consequently, it is recommended that deep draft vessels evade at sea when the area is threatened by an intense tropical storm (winds greater than 47 kt) or hurricane (winds greater than 63 kt). Early threat assessment is essential due to the elapsed time necessary to reach open water -- especially from Beaumont and Orange -- and the limited number of evasion routes available in the Gulf of Mexico.

Advice to small craft is to remove from the water. Otherwise, seeking shelter in the upper reaches of the Sabine and Neches Rivers above Orange and Beaumont is recommended.

Port Arthur is a small but important and active commercial shipping port. The Sabine-Neches Canal, on which the Port of Port Arthur is located, is also the deep water access to the nearby port of Beaumont and Orange. Because of their mutual access and close proximity to each other, all three ports are considered in this evaluation of Port Arthur as a hurricane haven.

History has demonstrated that the hurricane season presents a serious threat to marine activities in the Port Arthur area. Port Arthur has been affected by tropical cyclone activity at an average frequency of 0.9 events per year during the 109-year period 1871-1979. Since 1929, when hourly wind data was first recorded in the area, 1 out of 5 tropical storms/hurricanes passing within 180 n mi has caused sustained winds of 34 kt or greater at or near Port Arthur, but only 1 of the 56 tropical storms/hurricanes entering the 180 n mi threat radius caused winds of hurricane force to be recorded.

The hurricane season is late May through early November with September being the major threat month. The principal threat to Port Arthur is from tropical cyclones approaching from the southeast and south. Seventy-seven percent of all tropical cyclones entering the 180 n mi critical area in the 109-year period 1871 through 1979 approached from these sectors.

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This hurricane haven evaluation was prepared by  
R.D. Gilmore of Ocean Data Systems, Inc. (ODSI),  
Monterey, CA 93940.

## PORT ARTHUR, TX

### 1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

As shown in Figure XIII-1, the ports of Port Arthur, Beaumont, and Orange are located in the coastal section of extreme eastern Texas. Port Arthur is situated on the west bank of the Sabine-Neches Canal which borders the western edge of Sabine Lake (Figure XIII-2). Beaumont is located some 15 miles northwest of Port Arthur on the Neches River, while Orange is about 18 miles northeast of Port Arthur on the Sabine River. Sabine Pass, which is the seaward entrance to Sabine Lake, Sabine Lake itself, and the Sabine River form the southern portion of the Texas-Louisiana border.

From the Gulf of Mexico, Sabine Pass is entered from a Safety Fairway passing through Sabine Bank Channel, a sea bar channel and a jetty channel. Federal project depths are 42 ft in the outer bar channel, thence 40 ft through the jetty channel and Sabine Pass.\* Inside the Jetties, Sabine Pass extends northwest about 6 miles to Sabine Lake, and the entrance to Port Arthur Canal. With an average depth of 6 ft, Sabine Lake is used only by small recreation and fishing vessels. Port Arthur Canal extends northwest for about 6 miles from Sabine Pass to Taylor Bayou, with project depths of 40 ft (U.S. Department of Commerce, 1980).

The Neches River extends in a general west-northwesterly direction from its junction with the Sabine-Neches Canal for about 18.5 miles to the Port of Beaumont. Federal project depths on the Neches River are 40 ft to a 34-ft turning basin at Beaumont (U.S. Department of Commerce, 1980).

The Sabine River extends northeastward from its junction with the Sabine-Neches Canal to the Port of Orange. The Federal project provides for depths of 30 ft in the channel to Orange, with 25 ft maintained in the channel around Orange Harbor Island (U.S. Department of Commerce, 1980).

No bridges cross Sabine Pass, Port Arthur Canal, or Sabine-Neches Canal below Port Arthur. At Port Arthur, a fixed highway bridge with a clearance of 136 ft crosses the Sabine-Neches Canal approximately 1.8 miles above the entrance to Taylor Bayou. A highway bridge (Rainbow Bridge), with a clearance of 172 ft, crosses the Neches River about 1.5 miles above its mouth. No other bridges exist between Port Arthur and the turning basin at Beaumont, but overhead power cables with clearances of 164 ft cross the Neches River 50 yards east of Rainbow Bridge. Additional power cables cross the Neches River between its mouth and Beaumont but, in each case, the vertical clearance equals or exceeds 164 ft. No bridges cross the Sabine River between its mouth and Orange. An overhead power cable with a vertical clearance of 172 ft crosses the river about 3 miles below Orange (U.S. Department of Commerce, 1980).

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\* See Notice to Mariners and latest editions of charts for controlling depths.

# PORT ARTHUR, TX

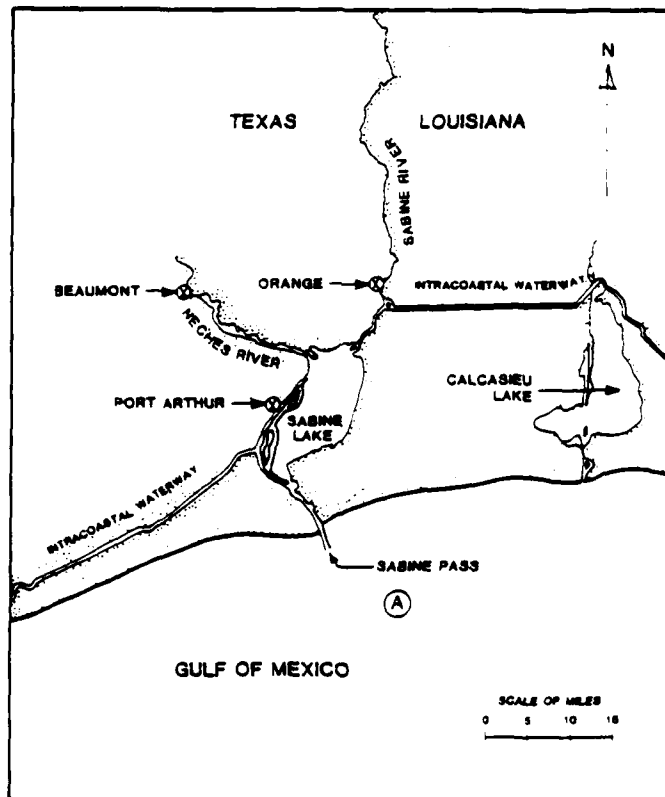


Figure XIII-1. Locations of Port Arthur, Beaumont, and Orange in southeast Texas.

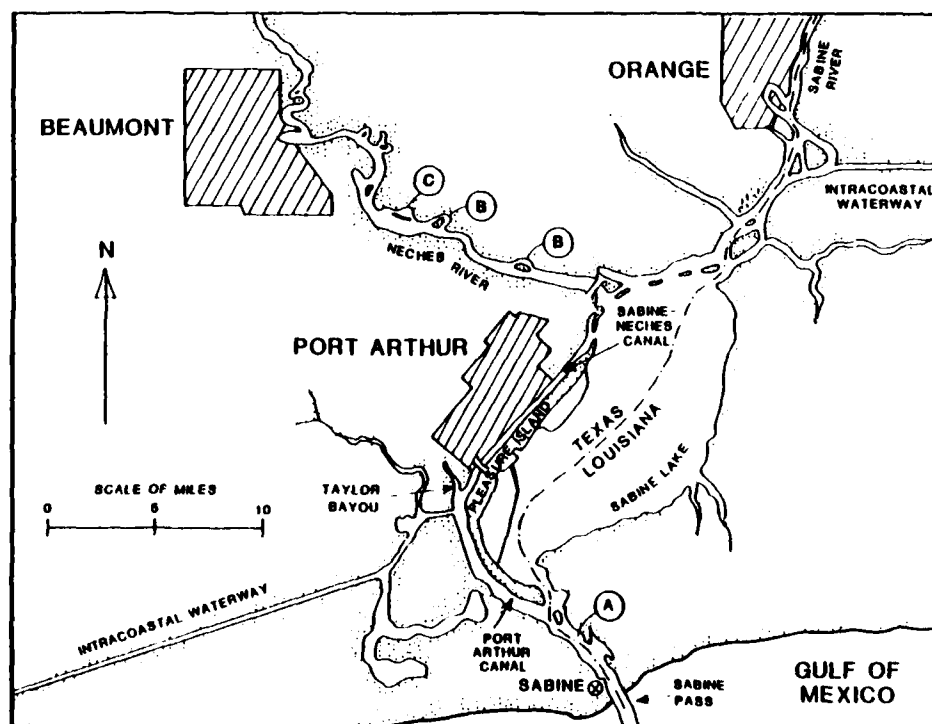


Figure XIII-2. Greater Port Arthur, Beaumont, and Orange area.



## PORT ARTHUR, TX

### 2. PORT AND HARBOR FACILITIES

#### 2.1 BERTHS FOR DEEP DRAFT VESSELS

##### 2.1.1 Port of Port Arthur

The Port of Port Arthur has over 50 wharves and piers, but only 12 are deep draft facilities. Of these, 11 are privately owned and operated, with alongside depths ranging from 27 to 43 ft (34-38 ft predominating), and deck heights of 6 to 15 ft.

The Port of Port Arthur Public Ocean Terminal Wharf (Figures XIII-3 and XIII-4) is owned and operated by the Port of Port Arthur Navigation District of Jefferson County, Texas. Located on the west side of Sabine-Neches Canal, it has a 1200 ft face with an alongside depth of 36 ft and deck height of 15 ft. More complete details of the piers, wharves, and docks at the Port of Port Arthur can be found in Port Series No.22 published in 1980 by the U.S. Army Corps of Engineers. The publication also provides details of 11 diesel tugs ranging from 1600 to 3900 horsepower used for towing, docking, and undocking vessels in Port Arthur, Beaumont, and Orange Harbors.

Other than a small U.S. Coast Guard pier, the U.S. Government does not maintain any harbor facilities at the Port of Port Arthur.

##### 2.1.2 Port of Beaumont

The Port of Beaumont has over 60 wharves and piers, but only 18 are deep-draft facilities. Of these, all but 8 are privately owned and operated, with alongside depths ranging from 32 to 40 ft and deck heights ranging from 10 to 16 ft.

The Port of Beaumont Navigation District owns and operates the remaining 8 deep-draft facilities (Figures XIII-5 and XIII-6). Located on the west bank of the Neches River, alongside depths range from 30 to 40 ft with an average alongside depth near 36 ft. Deck heights are a uniform 16 ft.

More complete details of the piers, wharves, and docks at the Port of Beaumont can be found in Port Series No. 22 published in 1980 by the U.S. Army Corps of Engineers.

No U.S. Government harbor facilities are maintained at the Port of Beaumont.

##### 2.1.3 Port of Orange

The Port of Orange has over 40 wharves and piers, but most are privately owned and not suitable for deep-draft vessels. Except for facilities owned and operated by Livingston Shipbuilding Company and the Port of Orange, most harbor facilities have alongside depths of less than 20 ft.

## PORT ARTHUR, TX

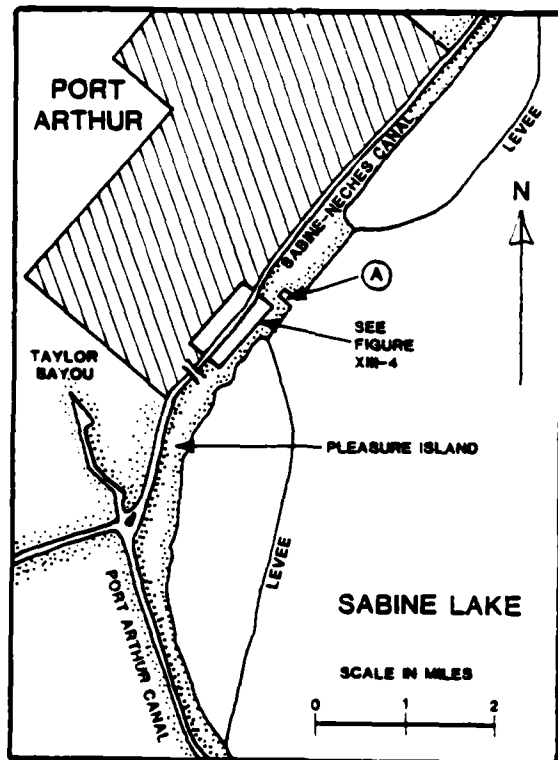


Figure XIII-3. Location of the port of Port Arthur on the Sabine-Neches Canal.

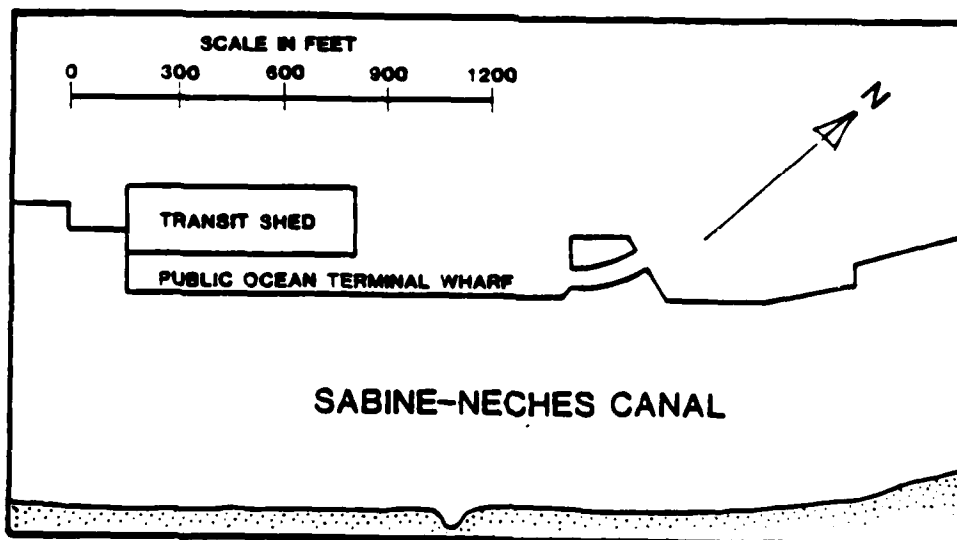


Figure XIII-4. Port of Port Arthur.

# PORT ARTHUR, TX

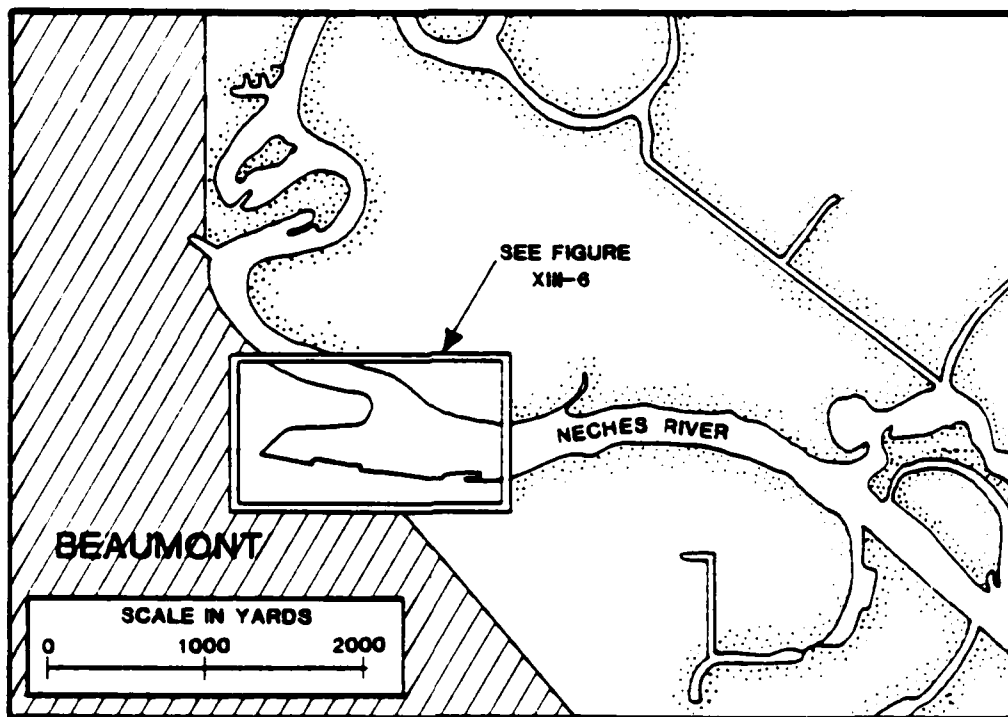


Figure XIII-5. Location of the Port of Beaumont on the Neches River.

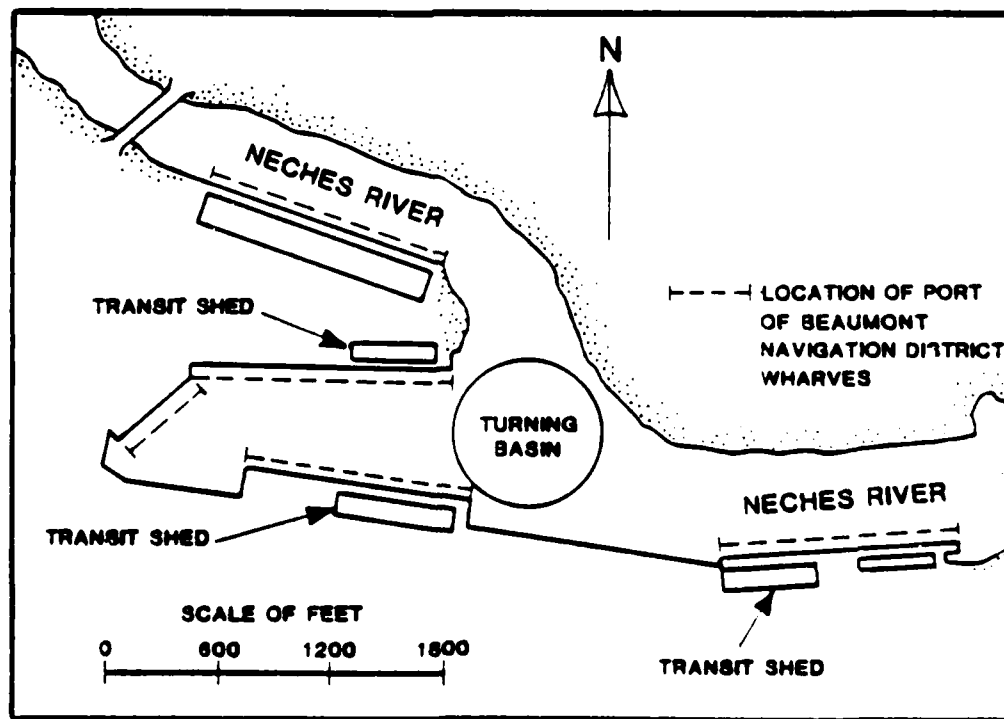


Figure XIII-6. Port of Beaumont.

## PORT ARTHUR, TX

The Port of Orange owns and operates the Alabama Street Wharf located on the Orange Municipal Slip, about 2 miles below the city on the west side of the Sabine River (Figures XIII-7 and XIII-8). Five berths are located on a 2300 ft wharf along the southwest side of the slip. Alongside depth is 30 ft with deck heights of 12 to 14.5 ft. In addition to the wharf at the Orange Municipal Slip, the Port of Orange has a Lay Berth Facility on the Sabine River about 2.7 miles above the slip (Figure XIII-9). Located on the west bank of the river, the facility consists of 9 (of 12) concrete piers previously owned by the U.S. Government and operated as part of the U.S. Navy Atlantic Fleet Reserve Base. Ranging in length from 480 to 900 ft, the piers have deck heights of 10 ft and minimum alongside depths of 18 ft, with depths near the river channel somewhat deeper. Maintenance of the river channel to a 30 ft depth ceases below the Lay Berth Facility, so exact channel depth adjacent to the piers is not specified.

More complete details of the piers, wharves, and docks at the Port of Orange can be found in Port Series No. 22 published in 1980 by the U.S. Army Corps of Engineers.

U.S. Government facilities at the Port of Orange are limited to Pier #10, with the piers being numbered sequentially starting with number 1 at the upstream end. It is used as a utility pier by the U.S. Navy and Marine Reserve Center, Orange, Texas. Piers 11 and 12 are used by Lamar University.

### 2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

None of the ports of Port Arthur, Beaumont, and Orange offers adequate shelter from heavy weather. The low elevation of the land surrounding the port limits the protection that orographic features usually provide and exposes the region to flooding in high water situations.

Anchorage for large vessels include the Sabine Fairway Anchorage outside the entrance to Sabine Pass as indicated by the letter "A" in Figure XIII-1. Vessels of light draft can find good holding ground along the coast 7 to 8 miles west of the jetties as close inshore as drafts will permit (U.S. Department of Commerce, 1980).

Additional anchorages include an anchorage basin, indicated by the letter "A" in Figure XIII-2, on the east side of Sabine Pass Channel. Federal project depth for the anchorage is 40 ft. Temporary anchorages exist in 29 ft of water in the bends of the old Neches River between the Sabine-Neches Canal and Beaumont and are indicated by the letter "B" on Figure XIII-2. With the exception of these temporary anchorages, only emergency anchorage is permitted in the Neches River. Vessels may tie up to the banks of the Neches and Sabine Rivers for a limited period provided permission is obtained from the Corps of Engineers (U.S. Department of Commerce, 1980). No anchorages exist on the Sabine River.

# PORT ARTHUR, TX

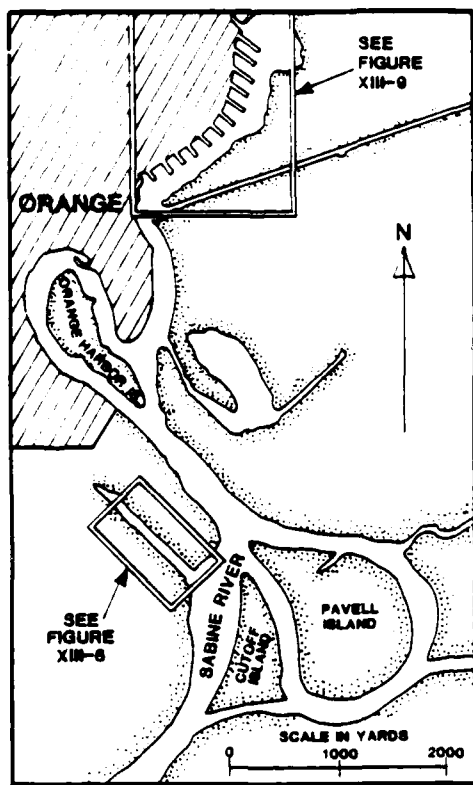


Figure XIII-7. Location of the Port of Orange on the Sabine River.

Figure XIII-9. Lay berth facility on the Sabine River, Port of Orange.

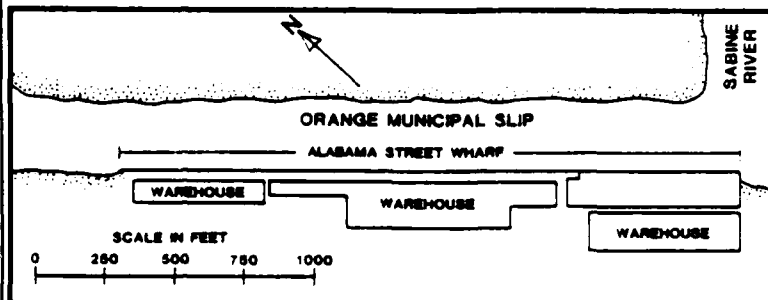
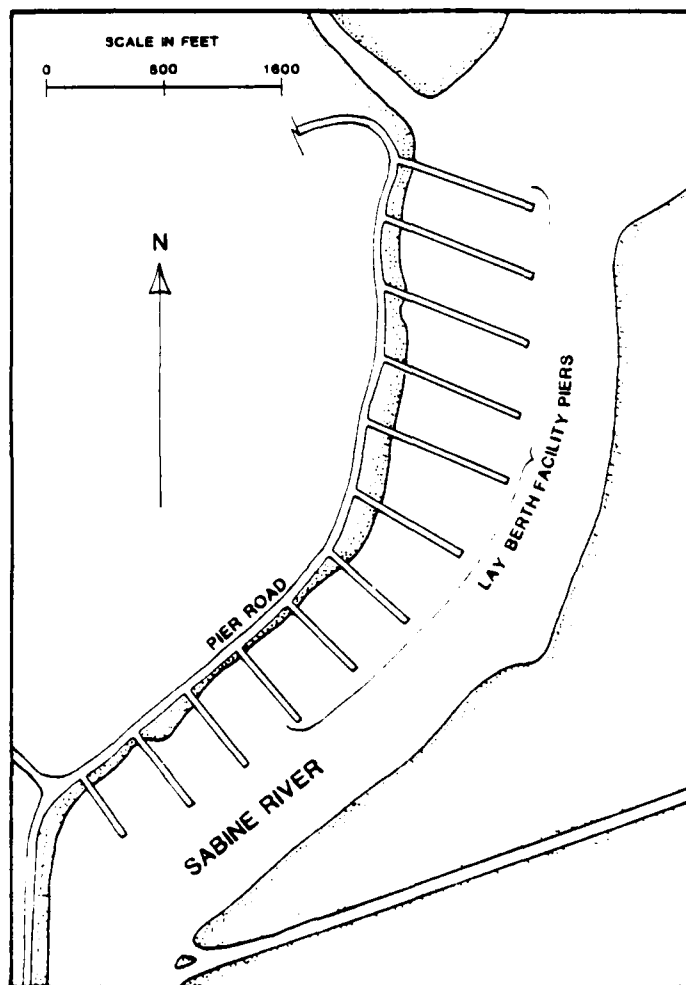


Figure XIII-8. Port of Orange, Alabama St. wharf.



## PORT ARTHUR, TX

The Maritime Administration has a restricted anchorage on the Neches River about 7 miles below Beaumont at the McFadden Bend Cut-off, as indicated by the letter "C" on Figure XIII-2. Capable of holding over 200 large vessels, it provides good holding ground in mud and silt, but maximum draft is limited to 16 ft. Use of the Maritime Administration anchorage is restricted to vessels consigned to the Maritime Administration Reserve Fleet.

In the event of damage, facilities are available at Port Arthur for making repairs to hulls and machinery, including dry-docking for vessels to 17,600 tons/650 ft (U.S. Department of Commerce, 1980).

### 2.3 FACILITIES FOR COASTAL AND IN-SHORE VESSELS

The main facility for recreational boaters in the Port Arthur area lies along the west shore of Sabine Lake on Pleasure Island adjacent to the Port of Port Arthur, as indicated by the letter "A" on Figure XIII-3. Called Pleasure Island Marina, its use is intended for boats drawing only 2 to 3 ft.

Small boats in the Sabine-Neches Canal can get fuel, oil, water and supplies along the Port Arthur city waterfront. Above Port Arthur, a marina and boatyard are located on the Neches River just west of the south end of Rainbow Bridge. Normal supplies are available, and the boatyard can handle vessels to 30 ft for hull and engine repairs. Depths of approximately 5 ft are carried to the marina and boatyard.

The city of Orange has a marina located on the west side of the channel opposite the north end of the Orange Harbor Island. Supplies, berths, and hotel accommodations are available. Alongside depths of 12 ft are reported at the fuel pier of the marina (U.S. Department of Commerce, 1980).

## 3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT PORT ARTHUR

### 3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight may be gained into their typical behavior. This background knowledge and understanding allows attention to be focused on those storms most likely to have a serious effect on the Port Arthur area. However, the historical behavior of storms and their impact on Port Arthur should not be regarded as a reliable guide to the detailed behavior and impact of a particular storm as it appeared in the past.

## PORT ARTHUR, TX

### 3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Port Arthur is considered to represent a threat to the area.

The outstanding feature of the U.S. Gulf Coast is its location on the north shore of the Gulf of Mexico and its orientation perpendicular to normal cyclone tracks as they move more or less northward out of the tropics. Also of importance is the region's position between 25 and 30 degrees north latitude; this is within the normal locus of tropical cyclone recurvature which oscillates between latitudes 25N and 35N during the tropical cyclone season. This latter factor is significant since it is the character of tropical cyclones to slow and intensify during the recurvature stage. During this phase of the tropical cyclone life cycle, it is difficult to predict with great accuracy the rate of recurvature, the storm speed of movement subsequent to recurvature, and obviously, the storm's precise future position at a point in time.

The hurricane season along the Gulf Coast is late May through early November. During the 109-year period from 1871 through 1979 there were 101 tropical cyclones that met the 180 n mi threat criteria for Port Arthur, an average of about 0.9 per year. Table XIII-1 shows the monthly totals and percentages. These data are graphically presented in Figure XIII-10. It is readily apparent that the frequency of tropical cyclone threat increases from May through September, then decreases significantly in October.

Table XIII-1. Monthly totals of tropical cyclones passing within 180 n mi of Port Arthur during the period 1871-1979.

Month	Number	% of Total
May	1	1.0
June	14	13.8
July	14	13.8
August	20	19.8
September	40	39.7
October	12	11.9

Figure XIII-11 illustrates the 101 events during the 109-year period as a function of compass octant from which tropical cyclones have approached Port Arthur. The numbers in parenthesis represent the percentage of cyclones from the sample approaching from a particular octant. The figure shows that the predominant threat sector extends from south through southeast. Seventy-seven percent of the tropical cyclones affecting Port Arthur have approached from those octants, with the greatest percentage (40%) approaching from the southeast.

# PORT ARTHUR, TX

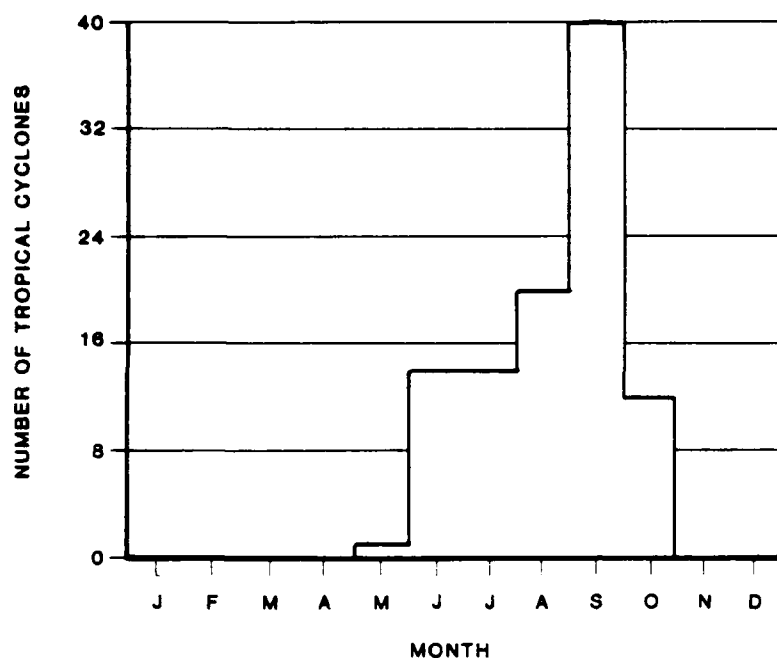
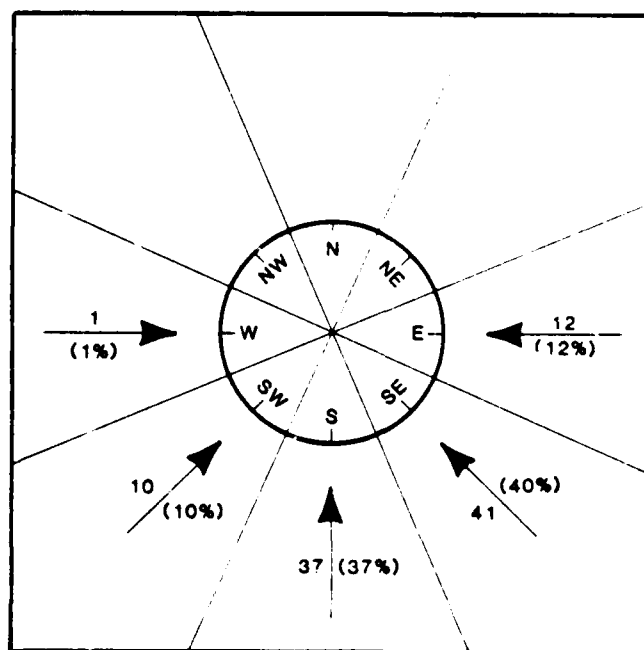


Figure XIII-10. Seasonal distribution of tropical cyclones passing within 180 n mi of Port Arthur, May-October (based on data from the period 1871-1979).

Figure XIII-11. Directions of approach of tropical cyclones that passed within 180 n mi of Port Arthur during the period 1871-1979. Numbers of storms approaching from each octant (e.g., 37) and percent of the total approaching from that octant (e.g., 37%) are shown.





## PORT ARTHUR, TX

One tropical cyclone formed within 180 n mi of Port Arthur, and developed quickly into hurricane strength after initial formation.

Records of tropical cyclones entering the 180 n mi critical area around Port Arthur during the 80-year period of 1900 through 1979 for which cyclone intensity data are available are tabulated in Table XIII-2 by intensity and month of occurrence. Of the 74 occurrences, it can again be seen that September is by far the principal threat month in terms of tropical cyclones affecting Port Arthur, but the highest monthly percentage of the more dangerous classes of storms (hurricanes and intense tropical storms) is in August (13 of 16). Overall, 47 out of 74 tropical cyclones (64%) affecting Port Arthur in this century were in these strong categories.

Table XIII-2. Classification of 74 tropical cyclones which passed within 180 n mi of Port Arthur during the 1900-1979 period.

Maximum Intensity*	May-June	July	Aug.	Sep.	Oct.	Totals
Hurricane	4	5	10	12	3	34
Intense Tropical Storm	3	0	3	6	1	13
Weak Tropical Storm	2	6	3	11	3	25
Tropical Depression	1	0	0	1	0	2
TOTALS	10	11	16	30	7	74

\*Intensity values reflect the maximum intensity while in the final approach phase of the tropical cyclone track. Upper limit of a weak tropical storm is 47 kt.

Figures XIII-12 through XIII-16 are statistical summaries of threat probability for the years 1871 through 1979. These summary data are presented in five charts, each representing data encompassing specific periods during the year: tropical cyclones occurring during May and June, July and August, September, and October, and all tropical cyclones of record during the 109-year period.

The solid lines in the figures represent the "Percent Threat" for any storm location. The dashed lines represent approximate approach time to Port Arthur based on the climatological approach speed for a particular storm location. For example, in Figure XIII-12, a tropical cyclone located over the northwest corner of the Yucatan Peninsula has a 30% probability of passing within 180 n mi of Port Arthur and will reach Port Arthur in 72-96 hours (3 to 4 days).

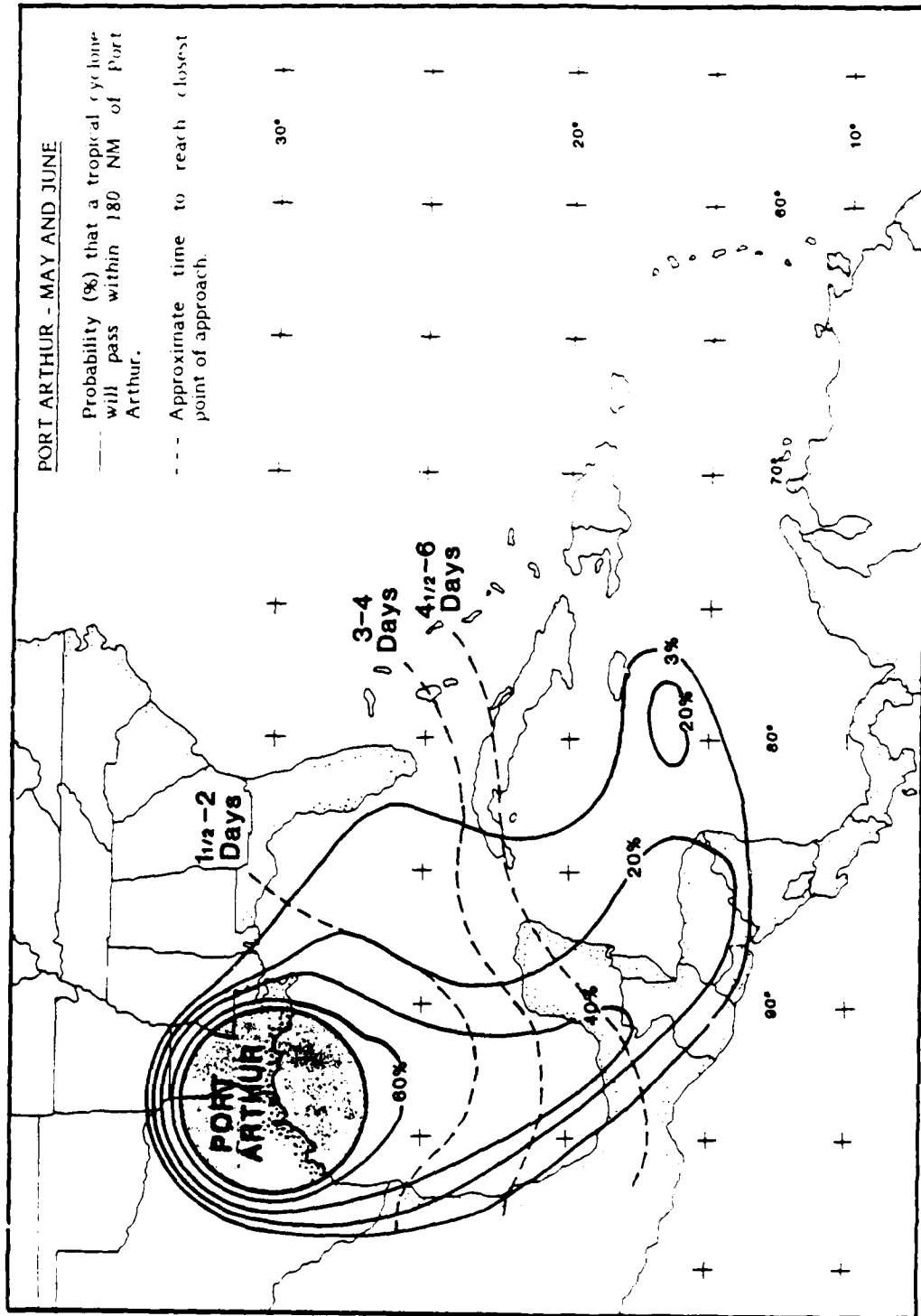


Figure XIII-12. Probability that a tropical cyclone will pass within 180 n mi of Port Arthur (shaded circle), and approximate time to reach closest point of approach, during May and June (based on data from 1871-1979).

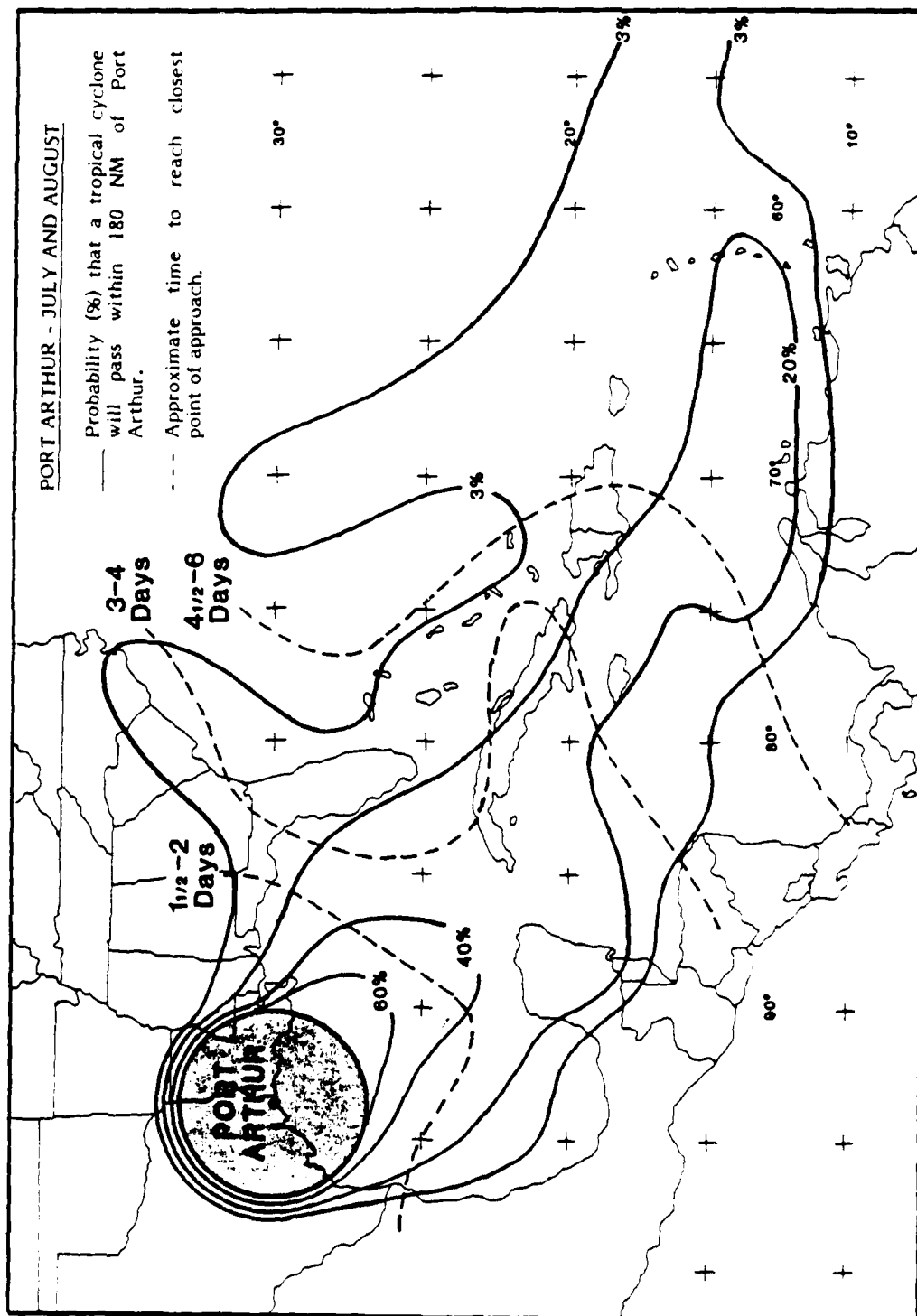


Figure XIII-13. Probability that a tropical cyclone will pass within 180 n mi of Port Arthur (shaded circle), and approximate time to reach closest point of approach, during July and August (based on data from 1871-1979).

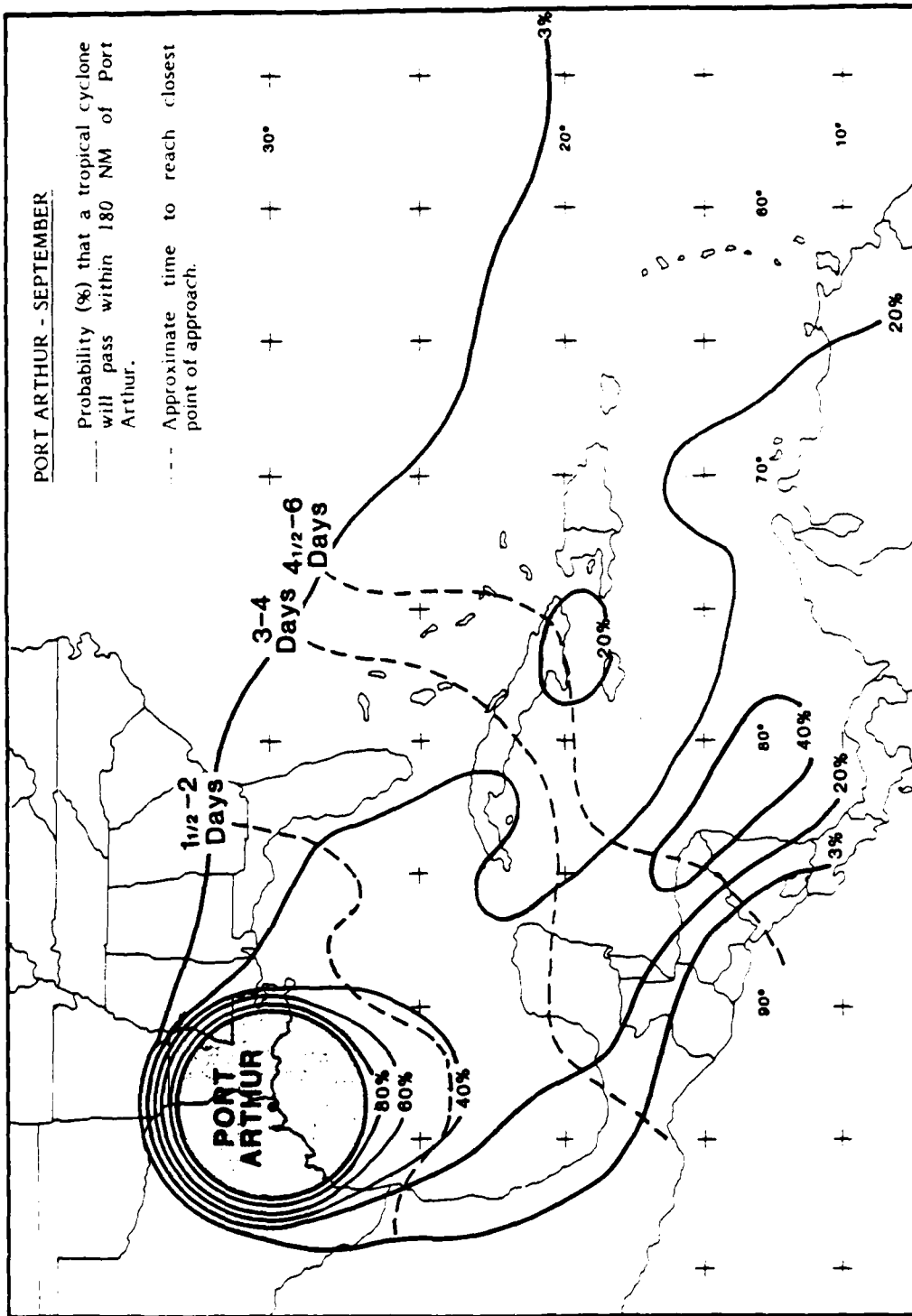


Figure XIII-14. Probability that a tropical cyclone will pass within 180 n mi of Port Arthur (shaded circle), and approximate time to reach closest point of approach, during September (based on data from 1871-1979).

# PORT ARTHUR, TX

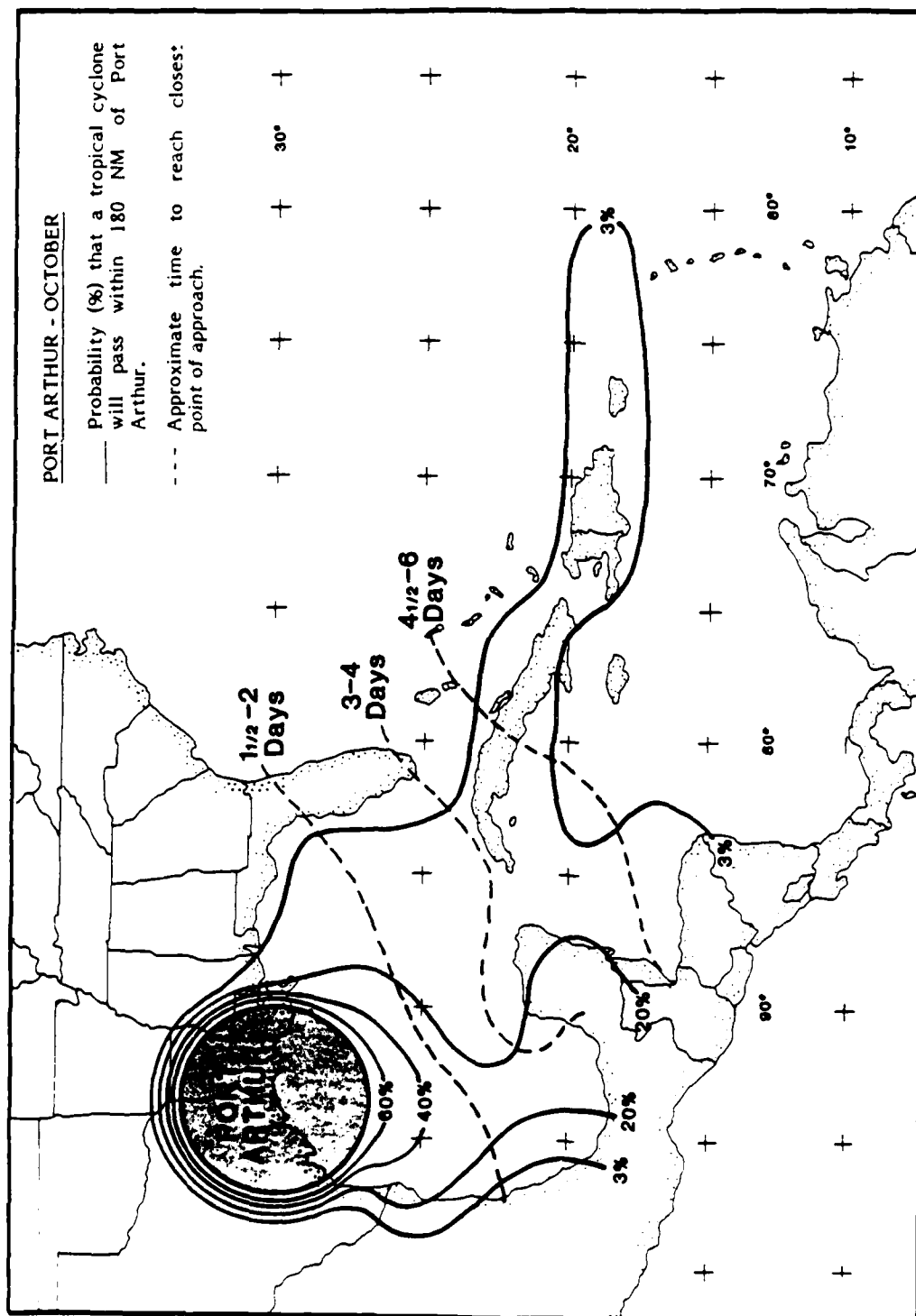


Figure XIII-15. Probability that a tropical cyclone will pass within 180 n mi of Port Arthur (shaded circle), and approximate time to reach closest point of approach, during October (based on data from 1871-1979).

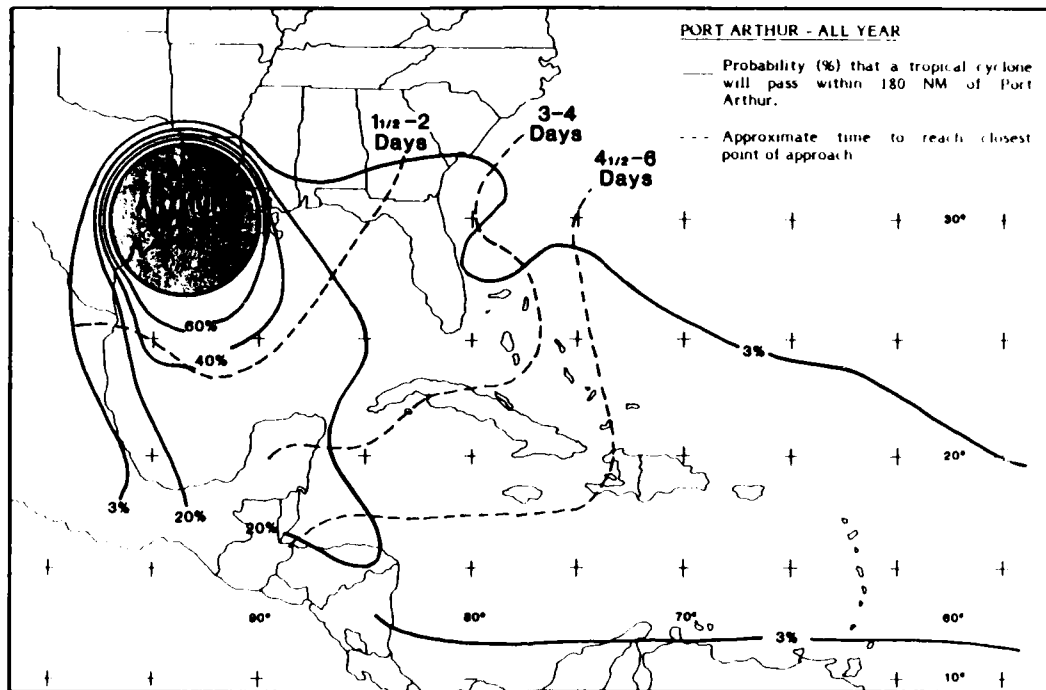


Figure XIII-16. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi (shaded circle) of Port Arthur, based on data from 1871-1979.

The average speed of advance for all tropical cyclones that have threatened Port Arthur is 7 to 8 kt, with little variation during the season. The most severe storms -- those with winds of 100 kt or greater -- moved at an average speed of 11 kt (Neumann and Pryslak, 1981).

A comparison of the figures suggests some distinct differences in the threat axis according to the time of the year. Early in the season (May and June, Figure XIII-12), the primary threat to the Port Arthur area is a track from the northern Caribbean Sea south of Jamaica westward along the coast of Honduras, across the southern Yucatan Peninsula into the Gulf of Campeche, thence northward across the western Gulf of Mexico to Port Arthur. A secondary, minor threat axis extends west-northwestward from the southern tip of Florida to Port Arthur.

By July and August (Figure XIII-13), the primary threat axis has shifted northward, originating in the eastern Caribbean Sea near the Lesser Antilles. It then extends west-northwestward, passing between Jamaica and Cuba before crossing the western tip of Cuba, thence into the Gulf of Mexico to Port Arthur.

In September (Figure XIII-14), the most active month, the primary track has shifted southward again, progressing westward from the coastline of northern Venezuela to the waters east of Nicaragua, thence northwestward across eastern Honduras to the Yucatan Peninsula. It then curves northward across the Gulf of Mexico to Port Arthur. A secondary but prominent axis approximates the primary

## PORT ARTHUR, TX

axis for July and August, passing through the waters between Jamaica and Cuba, thence west-northwestward across western Cuba and the Gulf of Mexico to Port Arthur.

By October (Figure XIII-15), the axis of greatest threat originates in the Gulf of Campeche and extends northward across the Gulf of Mexico to Port Arthur. A secondary threat axis originates north of the Lesser Antilles, and extends west-northwestward along the Greater Antilles to the Gulf of Mexico, thence northwestward to Port Arthur.

Figure XIII-16 presents a composite picture of threat probability and time to CPA curves for the entire year and is derived from all tropical cyclone tracks passing within 180 n mi of Port Arthur during the period 1871 through 1979.

### 3.3 WIND AND TOPOGRAPHICAL EFFECTS

A continuous record of wind data for any one location in the Port Arthur area is unavailable for the period 1929-1979. Therefore, tropical cyclone statistics contained herein are based on records as follows:

Sabine	July 1935-June 1954 September 1973-September 1979
Beaumont	June 1929-September 1943
Port Arthur	September 1944-September 1979

Consequently, tropical cyclone wind data are not based on records from a single location, but are considered to be representative of conditions experienced in the greater Port Arthur-Beaumont-Orange area.

In the 51-year period (1929-1979) for which wind data are available, 58 tropical cyclones approached within 180 n mi of Port Arthur. A tabular breakdown on intensity of these cyclones is shown in Table XIII-3.

Table XIII-3. Classification of the 58 tropical cyclones which passed within 180 n mi of Port Arthur between 1929 and 1979, based on the maximum intensity observed while within the 180 n mi radius.

<u>Hurricane</u>	<u>Tropical Storm</u>	<u>Tropical Depression</u>	<u>Total (No.)</u>
(≥ 63 kt)	(34 to 63 kt)	(≤ 34 kt)	
27	29	2	58

Out of the 56 tropical storms and hurricanes, 12 caused sustained winds greater than 33 kt in the Port Arthur area. Sixty-seven percent (8 of 12) approached from the southeast, with the remaining 33 percent approaching from the south. Only one tropical cyclone, Hurricane Audrey in June 1957, had wind gusts of hurricane strength recorded. Official hourly records since 1929 reveal

## PORT ARTHUR, TX

that no sustained hurricane force winds were experienced, but according to U.S. Army Corps of Engineers publication Sabine Lake Study Segment, Texas Coast Hurricane Study published in 1979, "On 8 August 1940 a minimal hurricane passed inland between Port Arthur and Sabine with sustained winds of 75 mph and peak gusts up to 95 mph." Based on official records only, gale force winds (34 kt or greater) can be expected from 1 out of every 5 tropical storms/hurricanes passing within 180 n mi of Port Arthur, and hurricane force winds from 1 out of every 56 tropical storms/hurricanes passing within 180 n mi.

Figure XIII-17 depicts the tracks of the 12 tropical cyclones that caused gale force winds in the Port Arthur area during the period 1940-1979 (Neumann, et al., 1978, Hebert, 1974, and Hebert, 1980). It should be noted that, although hourly wind data records were first maintained in 1929, no sustained gale force winds associated with tropical cyclones were recorded until 1940. Two-thirds (8 of 12) of the storms passed to the west of Port Arthur as they moved inland. Figure XIII-18 defines the tracks of the storm centers while winds of gale force were recorded at Port Arthur, Beaumont, or Sabine and clearly shows that the majority of tropical cyclones causing gale force winds in the area move inland west of Port Arthur, thereby placing Port Arthur in the more dangerous right-hand semicircle. It is significant to note that the region has not recorded gale force winds for any storm moving inland more than about 30 n mi east of Sabine Lake. Figure XIII-19 shows the direction from which recorded gale-force winds emanated. It supports a conclusion that Port Arthur is more likely to experience gale force winds from a southeasterly direction than any other.

### 3.3.1 Port Arthur

The Port of Port Arthur is exposed to winds from north-northeast clockwise to south-southwest. The only barrier to unimpeded wind flow from these directions is Pleasure Island, a long, narrow strip of land which forms the east shore of the Sabine-Neches Canal. Elevations of Pleasure Island are generally in the 5 to 15 ft range, with some small rises exceeding 20 ft. The only impediments to wind flow from south-southwest clockwise to north-northeast directions are the buildings of Port Arthur and the frictional effects of the surrounding marshlands.

### 3.3.2 Beaumont

The Port of Beaumont is exposed to winds with an easterly component. Limited protection is provided for winds from other directions by the buildings in the port area and the city of Beaumont, and by the frictional effects of the surrounding terrain. Low marshlands with elevations less than 5 ft lie to the east of the port and somewhat higher terrain with elevations exceeding 20 ft exists to the west.



# PORT ARTHUR, TX

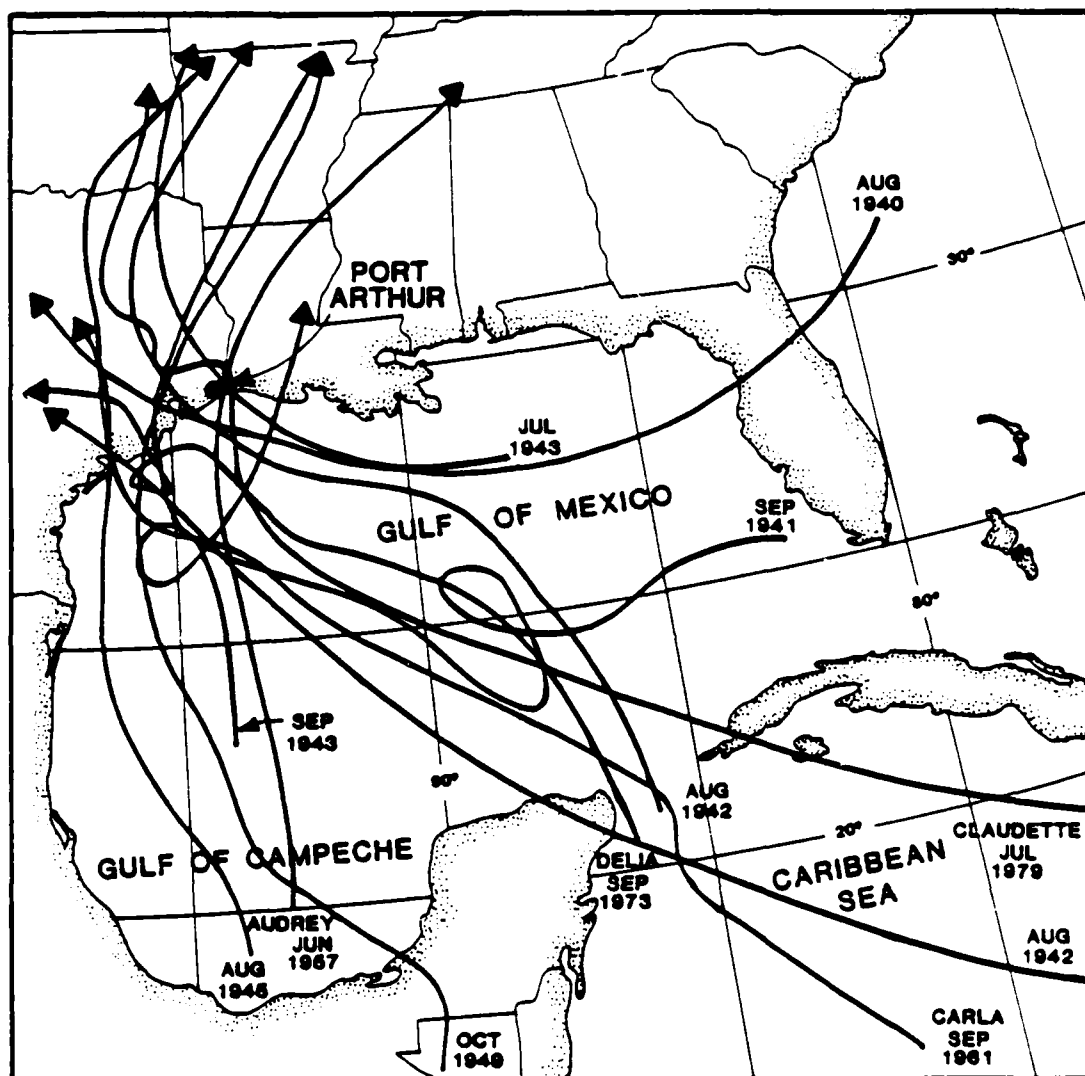


Figure XIII-17. Tracks of the 12 tropical cyclones during the period 1940-79 that caused sustained winds of 34 kt or greater in the Port Arthur area. Although records of hourly wind data have been kept since 1929, no gale force winds were recorded until 1940.

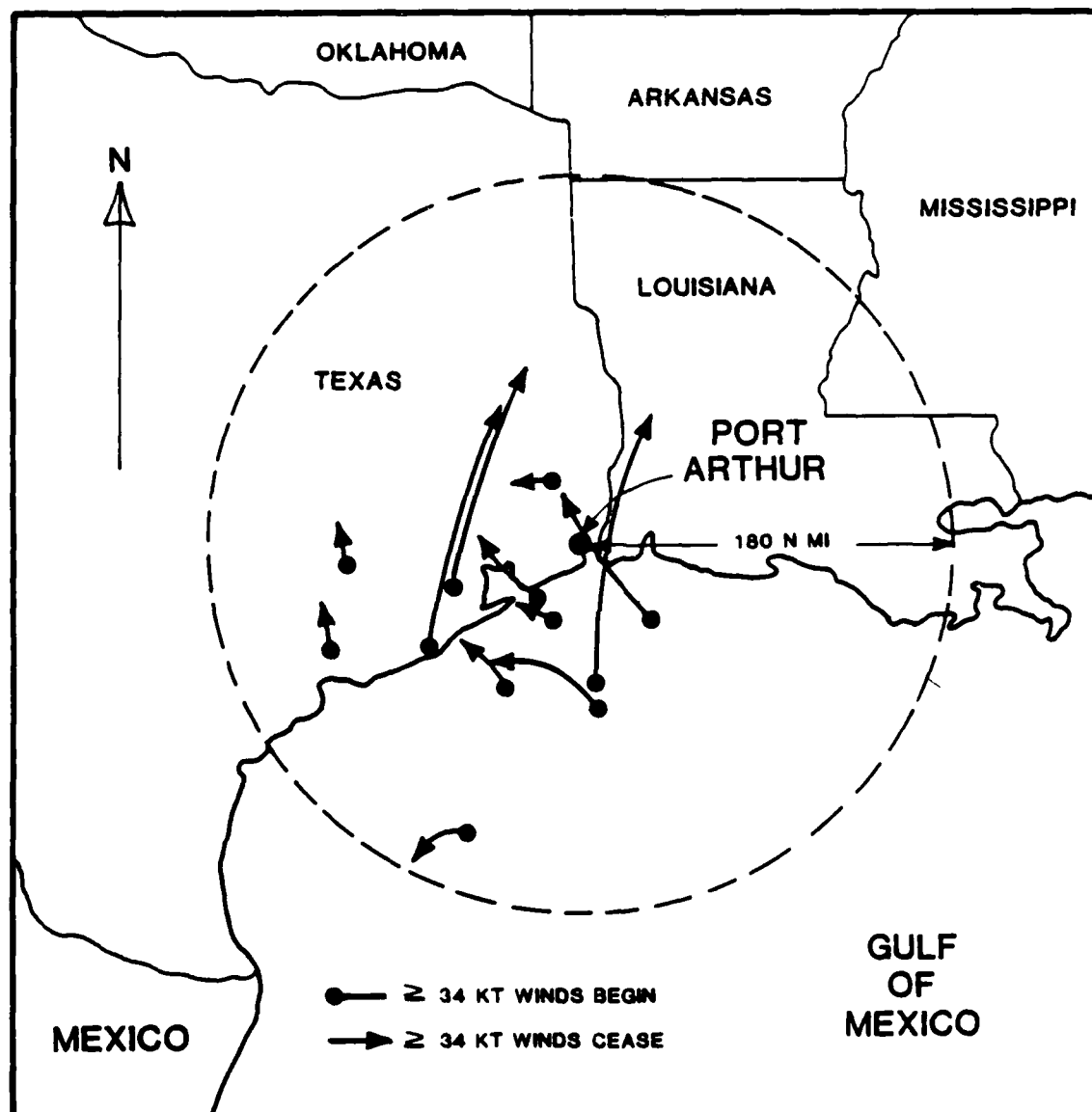


Figure XIII-18. Track segments of tropical cyclones 1940-79 showing storm positions when winds of 34 kt or greater were recorded in the Port Arthur area. Some bias in direction of movement and passing side is evident during the period, producing the predominance of south-easterly winds depicted in Figure XIII-19 (following page).

# PORT ARTHUR, TX

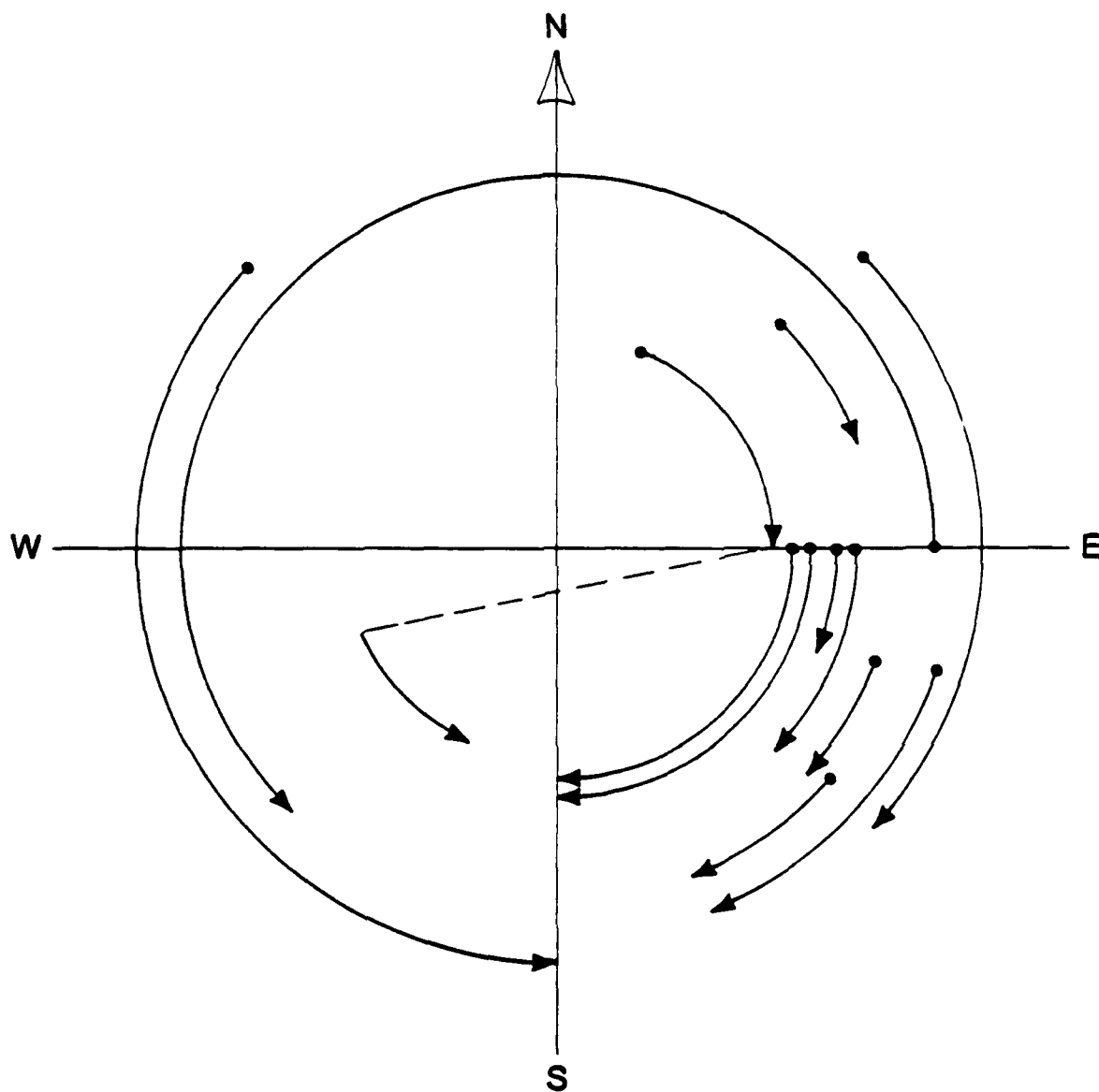


Figure XIII-19. Directions of winds 34 kt or greater in the Port Arthur area during passage of tropical cyclones 1940-79. Beginning and end of gale force winds shown by dot and arrowhead, respectively, as in Figure XIII-18. Clockwise direction changes indicate storm passage to the west, while counterclockwise changes indicate passage to the east. The two innermost arrows (connected by dashed line) reflect a direction shift, recorded when a storm passed over the recording station.

## PORT ARTHUR, TX

### 3.3.3 Orange

The Port of Orange is most vulnerable to southeasterly winds, as the Orange Municipal Slip is open in that direction. The expansive marshlands (with elevations generally less than 5 ft above MSL) opposite the slip on the east side of the Sabine River would provide only limited frictional effects to reduce wind speed. Slightly higher terrain north and west of Orange would furnish increased frictional effects and corresponding decreased wind speeds.

Low marshlands dominate the terrain in the eastern semicircle around the Lay Berth Facility. Consequently, the facility would be exposed to more-or-less unimpeded flow from any wind having an easterly component.

### 3.4 WAVE ACTION

Due to the locations of the Ports of Port Arthur, Beaumont, and Orange on relatively narrow waterways rather than on open bays and harbors, wave action is not considered to be a critical element in hurricane preparation planning for large vessels, but should be considered in any evolution involving small craft.

The wave height calculations in the following paragraphs are based on a uniform depth over a relatively flat bottom. Uniform depths are not realistic in the waterways serving the ports, as the channel is invariably deeper than the waters bordering it and the channel depth varies from one location to another. Consequently, the calculated values are for use as a guide only and should not be regarded as absolute values.

#### 3.4.1 Port Arthur

The location of the Port of Port Arthur on the Sabine-Neches Canal prevents significant wind waves if the wind is from any direction other than northeast. The canal, which is oriented on an approximate 040/220 degree axis, extends about 9 miles northeast of the port. Given a channel depth of 40 ft and a tidal surge of 5 ft for a water depth of 45 ft, and a wind blowing directly down the canal (northeast to southwest), the following wave calculations can be made: 25 kt winds, 3 ft wind waves; 35 kt winds, 4.5 ft wind waves; 50 kt winds, 6.5 ft wind waves; 75 kt winds, 9.6 ft wind waves; and 85 kt winds, 10.3 ft wind waves (U.S. Army Corps of Engineers, 1973).

It is emphasized that a slight change in wind direction, say 20 to 30 degrees in either direction, so that it is not blowing directly down the canal, would significantly reduce wave heights to a 2-3 ft chop.

## PORT ARTHUR, TX

### 3.4.2 Beaumont

The winding course of the Neches River east of Beaumont precludes long wind wave fetches. The maximum effective fetch length for wind waves in the Port of Beaumont is about 2 miles. With a channel depth of 40 ft and a tidal surge height of 5 ft for a water depth of 45 ft, and an easterly wind, the following wave calculations can be made: 25 kt winds, 1.7 ft wind waves; 35 kt winds, 2.5 ft wind waves; 50 kt winds, 3.9 ft waves; 75 kt winds, 5.9 ft wind waves; and 85 kt winds, 6.9 ft winds waves (U.S. Army Corps of Engineers, 1973). The heights given would occur only at the west end of the port with reduced heights elsewhere.

### 3.4.3 Orange

The location of the Port of Orange on the Orange Municipal Slip effectively precludes significant wave action at the port. With a channel depth of 30 ft and a 5 ft tidal surge for a water depth of 35 ft, and a southeasterly wind blowing through the slip parallel to the pier, the following wave calculations can be made: 25 kt winds, 1.3 ft wind waves; 35 kt winds, 1.9 ft wind waves; 50 kt winds, 2.9 ft winds waves; 75 kt winds, 4.3 ft wind waves; and 85 kt winds, 5 ft wind waves (U.S. Army Corps of Engineers, 1973). The wave heights given would occur only at the northwest end of the slip with reduced heights elsewhere. Similar heights would be expected in the river channel adjacent to the Lay Berth Facility with northeast or southwest winds, but, because the piers are oriented cross-channel, alongside areas of the piers would be protected from any significant wave action.

## 3.5 STORM SURGE AND TIDES

Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles right of its path. This dome height is related to local pressures (i.e., a barometer effect based on intensity of the storm) and to the local winds. Other significant contributing factors are storm speed, direction of approach, bottom topography, and coincidence with the astronomical tide.

The worst circumstances (Harris, 1963) would include the following:

1. Intense storm approaching perpendicular to the coast with landfall within 30 n mi to the west.
2. Broad, shallow, slowly shoaling bathymetry.
3. Coincidence with high astronomical tide.

## PORT ARTHUR, TX

The Gulf Coast shoreline adjacent to Port Arthur fulfills the bathymetry criteria and renders the Port Arthur area susceptible to storm surges.

History has shown that the Port Arthur area is vulnerable to the occurrence of destructive storm surge associated with tropical cyclones. The vulnerability of the area has been proven by two storms of recent memory, Hurricane Audrey in June 1957, and Hurricane Carla in September 1961. Audrey, which moved inland some 16 miles east of Sabine Pass, was one of the most severe hurricanes to strike the coast of the United States in the month of June. It generated a surge of 9.4 ft above MSL at Sabine Pass, with 5.6 ft above MSL recorded at Port Arthur and 4.5 ft above MSL recorded at Beaumont. Several lives were lost, and over 1.5 million dollars of damage was suffered in the area. Hurricane Carla, the largest storm to strike the Texas coast since 1900, crossed the coast approximately 200 miles southwest of Sabine pass, but surge heights of 9.4 ft above MSL at Sabine Pass, 7.6 ft above MSL at Port Arthur, 8.5 ft above MSL at the mouth of the Neches River, 8.1 ft above MSL on the north shore of Sabine Lake, and 7.4 ft above MSL on the Sabine River at Orange were recorded. The surge inundated 40 percent of the Port Arthur area, with millions of dollars in damage suffered (U.S. Army Corps of Engineers, 1979).

Sixteen tropical cyclones have had significant effects on the Port Arthur area since 1900. Of these, 4 have caused surges of 7 ft or more above MSL at Sabine Pass, with 3 exceeding 9 ft. For those causing surges of over 9 ft above MSL at Sabine Pass, Port Arthur recorded surges exceeding 7 ft above MSL in two instances and over 5 ft in the other, with these occurring in 1915, 1957, and 1961. Figure XIII-20 shows the tracks of the three hurricanes.

Several similarities exist between Hurricane Carla and the 1915 storm. Both originated outside the Gulf of Mexico and, after entering the Gulf of Mexico through the Yucatan Channel, maintained hurricane strength as they followed parallel tracks to the Texas coast; and both recurved after making landfall. Hurricane Audrey, an early season storm, developed in the Gulf of Campeche and moved northward, crossing the coast just east of Sabine Pass before recurving northeastward. Audrey's track closely approximates the maximum probability threat track shown in Figure XIII-12.

# PORT ARTHUR, TX

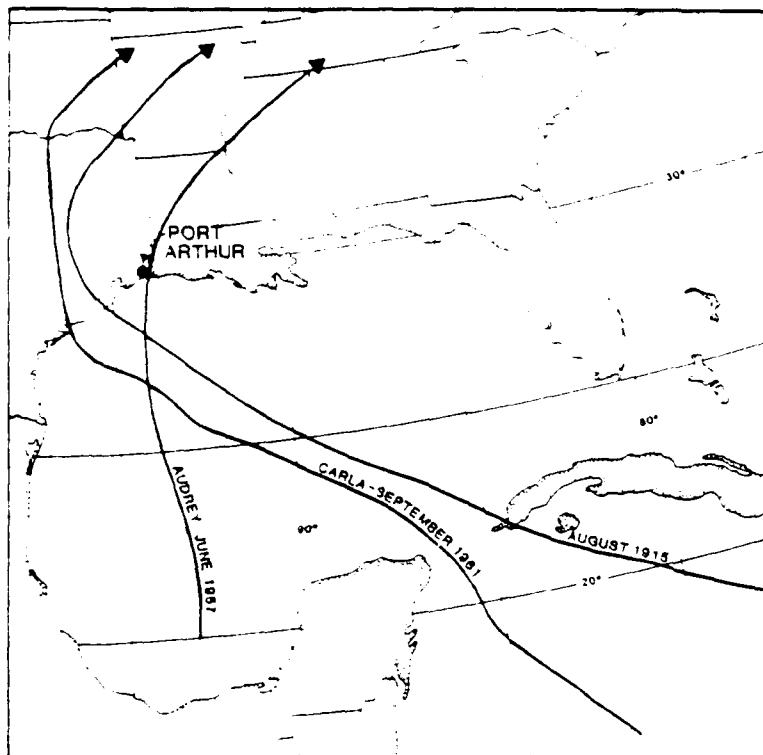
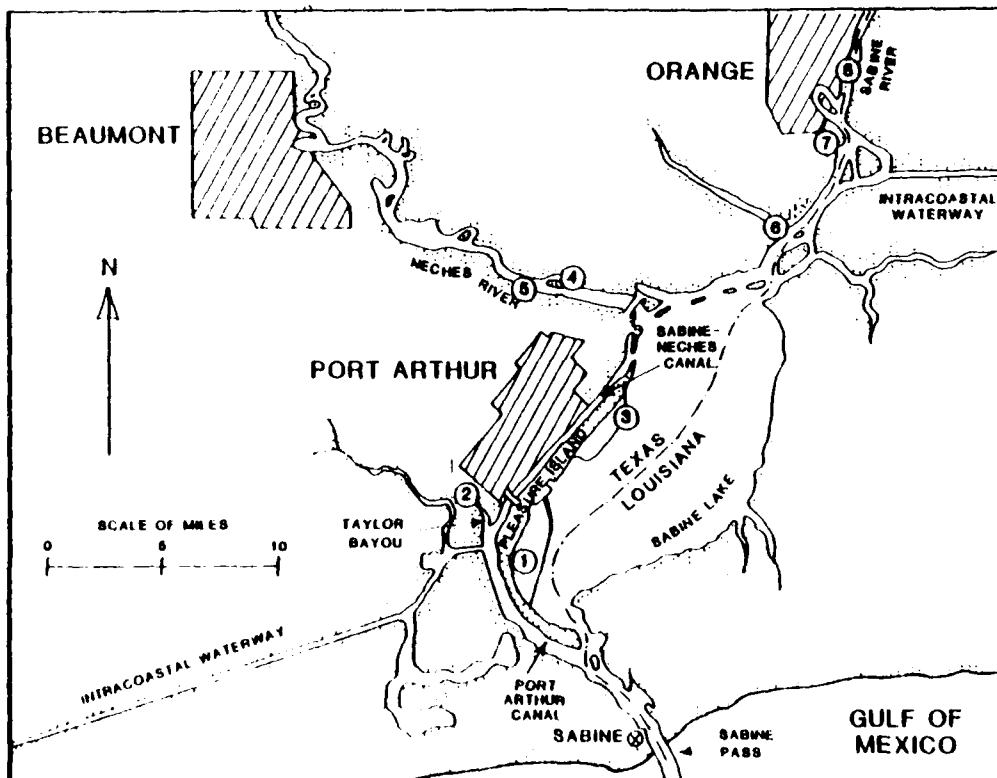


Figure XIII-20. Tracks of three tropical cyclones that produced storm tides of 9 ft or greater at Sabine Pass and 5 ft or greater at Port Arthur.



XIII-26 Figure XIII-21. Storm surge height locations, as listed in Table XIII-4.

## PORT ARTHUR, TX

The U.S. Army Corps of Engineers has developed tidal flood estimates for a hypothetical "100-Year Frequency Hurricane." In addition, they have developed estimates for the "most severe tropical storm that is considered to be reasonably characteristic of the geographical area involved," referred to as the "Standard Project Hurricane" (U.S. Army Corps of Engineers, 1968). The 100-Year Hurricane and Standard Project Hurricane values for various locations in the Port Arthur area as shown in Figure XIII-1 are given in Table XIII-4.

Table XIII-4. 100-Year Frequency Hurricane and Standard Project Hurricane induced water heights for locations in the Port Arthur area (U.S. Army Corps of Engineers, 1968). Combined effects of high astronomical tide and storm surge on high water levels associated with landfalling hurricanes approaching perpendicular to the shoreline adjacent to Port Arthur. Heights in the middle column would occur once in 100 years on the average, and those in the right column can be described as "worst-conceivable." All heights in feet above MSL.

Location	Location Code*	100-Year Frequency Hurricane	Standard Project Hurricane
Southwest Sabine Lake	1	14	16
Taylor Bayou	2	13	15
Northwest Sabine Lake	3	14	16
Neches River	4	13.5	15.5
Port Neches	5	14	16
Adams Bayou	6	13.8	17.2
Orange Municipal Ship	7	13.8	17.2
Lay Berth Facility	8	13.8	17.2

\*See Figure XIII-21.

A tidal surge of the magnitude of a 100-Year Frequency Hurricane or Standard Project Hurricane would inundate most of the land area between Beaumont, Orange, and Port Arthur. Some areas of Beaumont would be flooded, but most of the city is above flood level. Not so, however, for Orange. A tidal surge of the heights given in Table XIII-4 could result in water depths up to 9 ft in the downtown area (U.S. Army Corps of Engineers, 1968). Most of the area surrounding Port Arthur would be flooded, but a recently completed levee system is designed to protect the city itself from major flooding.



## PORT ARTHUR, TX

Astronomical tides at the jettied entrance to Sabine Pass range about 2.5 ft and 1.5 ft at Port Arthur. Periodic tides are negligible on the Sabine and Neches Rivers. Tidal currents between the jetties at Sabine Pass average 1.1 kt at flood tide and 1.6 kt on the ebb, with a maximum velocity of 2.5 kt observed (U.S. Department of Commerce, 1980). Current velocities on the Sabine and Neches rivers depend largely on water runoff from precipitation. Maximum channel velocities on the Sabine River that would occur as a result of flooding have been calculated to be about 4.6 kt (8 ft per second). Because tropical cyclones are usually accompanied by heavy precipitation, similar maximum velocities are possible with the passage of a tropical cyclone. Velocities resulting only from floods caused by hurricane tides, rather than precipitation, are not expected to be significant (U.S. Army Corps of Engineers, 1968).

### 4. THE DECISION TO EVADE OR REMAIN IN PORT

#### 4.1 THREAT ASSESSMENT

For the masters of deep-draft vessels, the lack of protected alongside berths and the elapsed time required to negotiate the ship channels leading to open water in the Gulf of Mexico make early assessment of each tropical cyclone threat essential. This assessment should be related to the setting of hurricane conditions of readiness by U.S. Navy, U.S. Coast Guard, and civil authorities, and conducted using current advisories and forecasts issued by the Navy and National Weather Service, and climatology presented herein.

As can be seen in Figures XIII-12 through XIII-16, the greatest threat of strong winds in the Port Arthur area comes from tropical cyclones which follow one of two main tracks. Seventy-five percent (9 of 12) of the tropical cyclones which caused sustained winds of gale force (Figure XIII-17) followed these tracks, with 5 entering the Gulf of Mexico from the Caribbean Sea and following a northwesterly course to the Texas coast. Four storms, including Hurricane Audrey, originated in or near the Gulf of Campeche and moved northward to the coast. Hurricane Audrey is the only tropical cyclone to cause winds of hurricane force to be recorded in the Port Arthur area.

While the greatest threat of storm surge occurs when tropical cyclones approach more or less perpendicular to the coast and make landfall within 75 n mi west and 30 n mi east of Sabine Pass, any storm causing sustained winds with a strong southerly component in the Port Arthur area could produce a significant storm surge. A prime example of this situation is Hurricane Carla of September 1961 (Figure XIII-20). Carla made landfall some 200 miles southwest of Sabine Pass, yet caused a tidal surge of near record levels in the Port Arthur area.

## PORT ARTHUR, TX

The individual storm intensity and speed of movement affect the extent of damage that can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that Port Arthur is located in the dangerous right front quadrant of the storm can result in severe wind and storm surge conditions. The months of maximum threat in terms of frequency and severity are August and September.

### 4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy deep draft vessels when the port is under threat from an intense tropical cyclone approaching from the Gulf of Mexico and which threatens to landfall within 100 n mi west or 50 miles east of Sabine Pass. Timing of this decision is affected by:

- (1) The forward speed of the tropical cyclone.
- (2) The radius of hazardous winds and seas that can impact on a vessel's capacity to reach open water and then maneuver to evade.
- (3) The elapsed time to make preparation to get underway.
- (4) The elapsed time to reach open water.

For example:

The worst case situation would be an intense tropical cyclone moving more or less perpendicular toward Port Arthur from the south. Assume 6 hours are required to make preparations for leaving port after the decision to evade at sea is made, and assume another 4 hours are required to transit the channels enroute to deep water in the open sea. (If the vessel were departing Beaumont or Orange, the transit time would increase by 3-5 hours.) A tropical cyclone approaching at an average speed of 10 kt will have moved 100 n mi closer to Port Arthur by the time open water is reached and the vessel is about 20 n mi closer to the cyclone. Add to this the radius from the tropical cyclone center of strong winds likely to hamper harbor operations, say 200 n mi. Summing these values gives 320 miles (20+100+200) or 32 hours (at a 10 kt speed of advance) as the minimum tropical cyclone displacement from Port Arthur in distance or time when the decision must be made to evade at sea successfully. A greater margin may be applicable depending on greater cyclone speed and intensity, and speed capability of the vessel.

Hurricane Condition III is set when hurricane force winds are possible within 48 hours. It is apparent that the decision to prepare for sortie should be made soon after setting Hurricane Condition III. Although at this time the

## PORT ARTHUR, TX

storm center may be more than 500 miles distant, it should be remembered that the average tropical cyclone forecast error over a 48-hr period is on the order of 220 miles for those tropical cyclones threatening Port Arthur. Later departures wager the accuracy of information on the storm's behavior against mounting risks of heavy weather damage.

Once sea room is attained, the tactics employed will, of course, depend on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement. Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information with today's satellite technology is accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity, and movement.

Ship masters with access to these advisories/warnings are in the best possible position to modify evasion routes and tactics, as required, to successfully evade the storm. The cardinal rule of seamanship is to avoid the dangerous right-hand semicircle. The following guidelines are offered:

(1) For tropical cyclones approaching from the east or southeast: Steam southwest to increase distance from the storm while taking advantage of following winds and seas. Because of the shape of the Texas coastline west of Port Arthur, maneuvering room is restricted; a fact which must be considered before an evasion to the southwest is attempted.

(2) For tropical cyclones approaching from the southwest: After an early departure to avoid the worst effects of headwinds and seas, steam south or southeast to reach a latitude south of the cyclone center.

(3) For tropical cyclones approaching from the south: Tropical cyclones moving across the Gulf of Mexico in a northerly direction present the most vexing of evasion problems. Many storms move directly into the coast early in the season, but in September and October there is a strong likelihood of cyclone recurvature to the northeast while still centered over the Gulf. An evasion route decided on earlier may have to be altered based on unexpected changes in cyclone movement. Evasion tactics must be based on the latest tropical cyclone forecast position and movement.

### 4.3 RETURNING TO HARBOR

The damage and disarray at a port resulting from a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Also, since each of the Ports of Port Arthur, Beaumont, and Orange is accessed by narrow channels, the potential for such hazards is large. Harbor facilities may be so damaged as to preclude offering even minimal services. Check with the Port Authority before attempting to return.

#### 4.4 REMAINING IN PORT

Remaining in port at Port Arthur, Beaumont, or Orange is an option that should receive serious consideration whenever a vessel is incapable of successful evasion at sea or in secondary threat situations, including:

- (1) A tropical cyclone developing within the 180 n mi radius critical area.
- (2) A weak tropical cyclone approaching from the Gulf of Mexico and forecast not to intensify.
- (3) A tropical cyclone approaching overland from the east or west.
- (4) A tropical storm/hurricane expected to approach within 180 n mi and make landfall more than 100 n mi west or 50 miles east of Sabine Pass.

If a decision is made to remain in port, and if vessel draft is sufficiently shallow, use of the Port of Orange Lay Berth Facility (Figure XIII-9) is recommended. The strength of the concrete piers makes it more acceptable than the marginal wharfs at the Orange Municipal Slip and Port Arthur. Wind speeds at Beaumont would be somewhat reduced due to friction, but local authorities express concern regarding the strength of the bollards and bits on all but one wharf at Beaumont, and consider them unacceptable in a hurricane wind situation. If vessel draft or non-availability precludes use of the Lay Berth Facility at Orange, few desirable options remain. Securing the vessel to the most structurally sound wharf available is recommended, using sufficient lines to withstand hurricane force winds yet allow for water height fluctuations of the predicted amounts. Bow and stern "insurance lines" of heavy wire rope are recommended.

Riding out a tropical cyclone at anchor is an alternative that should be considered only in an extremely weak tropical cyclone threat situation. Except for the Maritime Administration anchorage, none of the anchorages shown on Figure XIII-2 have the qualities necessary for a good heavy-weather anchorage. Since Maritime Administration permission would have to be obtained, and drafts are limited to 16 ft or less, use of the Maritime Administration anchorage would be restricted to only the most exceptional cases.

#### 5. ADVICE TO SHALLOW DRAFT VESSELS

Shallow draft vessels should, if feasible, be removed from the water and firmly secured ashore at an elevation of at least 20 ft to avoid possible high water. Short of this it is recommended that small craft seek shelter in the upper reaches of the Neches River above Beaumont or the Sabine River above Orange. The U.S. Coast Guard at Port Arthur, upon the setting of Hurricane Condition One by the Eighth Coast Guard District, sends its small craft to the

## PORT ARTHUR, TX

Sabine River at Orange. It should be borne in mind that southerly winds and storm surge, coupled with upriver precipitation runoff, may cause extensive flooding.

The following extract from U.S. Coast Pilot 5 (U.S. Department of Commerce, 1980) is relevant: "Hurricane moorings. On receiving advisory notice of a tropical disturbance small boats should seek shelter in a small winding stream whose banks are lined with trees, preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of the trees will act as fenders and the branches, having more give than the trunks, will ease the shocks of the heavy gusts. If the banks are lined only with small trees or large shrubs, use clumps of them within each hawser loop. Keep clear of any tall pines as they generally have shallow roots and are more apt to be blown down."

Using open water anchorages to ride out the passage of a tropical cyclone is extremely hazardous. Virtually no protection is afforded except near the lee shore. Wind wave activity can be quite destructive, not to mention the hazards of floating debris resulting from the effects of wind waves, high water, and high winds.

The prudent small boat operator will have selected several potential havens beforehand in which to take shelter in various tropical cyclone threat situations. He will proceed to his haven well in advance to avoid the chaos and congestion endured by his fellow boaters who delay until the onset of destructive conditions is imminent.

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XIV. TAMPA, FL

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## XIV. TAMPA, FLORIDA

### SUMMARY

Tampa's location in the hurricane belt, lack of sheltered facilities, and vulnerability to storm surge render it a poor hurricane haven. Evasion at sea is recommended for all seaworthy deep-draft vessels when Tampa is threatened by an intense tropical storm or hurricane approaching from the Gulf of Mexico, or hurricane approaching overland across the Florida Peninsula.

Small craft should be removed from the water and firmly secured above the predicted high water line. Otherwise, seeking shelter in the upper reaches of the Hillsborough, Alafia, or Little Manatee Rivers is recommended.

Located on the west coast of the Florida Peninsula, Tampa is the largest port in Florida and the 7th largest port in the United States. No U.S. Navy ships are home-ported in Tampa, but MacDill Air Force Base is a prominent military presence.

Tampa has been threatened by an average of 1.6 tropical cyclones per year, of which 1 out of 5 caused sustained winds of gale force in the Tampa area. While there are 4 recorded instances of sustained 50 kt winds during the years 1932-1979, only one tropical cyclone caused sustained winds of hurricane strength.

The hurricane season is late May through early November, but Tampa has been threatened by tropical cyclones as early as February and as late as December. The months of maximum occurrence are September and October, but June is a strong threat month for tropical cyclones moving northward from the western Caribbean Sea.

Although the landmass of the Florida Peninsula lies east of Tampa, it affords little protection from tropical cyclones. History has shown that Tampa is vulnerable to tropical cyclones approaching from all directions. Forty-two percent of all tropical cyclones causing sustained winds of gale force to be recorded in the area had trajectories that carried them over a large portion of the landmass southeast of Tampa prior to affecting Tampa.

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This hurricane haven evaluation was prepared by  
R.D. Gilmore of Ocean Data Systems, Inc. (ODSI),  
Monterey, CA 93940.

XIV-1

Change 1

## TAMPA, FL

### 1. GEOGRAPHICAL LOCATION AND TOPOGRAPHY

Tampa is located at the approximate mid-point on the west coast of the Florida Peninsula. As shown in Figure XIV-1, the city and Port of Tampa lie at the north end of Hillsborough Bay, an arm of Tampa Bay. Approximately 6 to 7 miles wide and some 20 miles long, Tampa Bay serves not only as access to the Port of Tampa, but also the Port of St. Petersburg, Port Tampa, and Port Manatee.

As is the case with many of the areas on the Gulf Coast, the lands surrounding Tampa Bay are generally low in elevation, and much of the low-lying real estate has been developed for homesites or industrial purposes. Except for a section of southern Pinellas Peninsula, few elevations reach 30 ft within 3 miles of the bay.

For deep-draft vessels, the main ship channel passes between Egmont Key and Mullet Key into a dredged cut that enters Tampa Bay (Figure XIV-1). A Federal project provides for depths of 36 ft in the entrance from the Gulf of Mexico, thence 34 ft to Tampa and Port Tampa (U.S. Department of Commerce, 1980).\*

Southwest Channel, a natural passage south of Egmont Key, has a controlling depth of about 16 ft but is subject to shoaling (U.S. Department of Commerce, 1980). Use of Southwest Channel is not recommended for ocean going vessels except those with very shallow drafts.

Water depths in Tampa Bay vary significantly from one location to another, but are generally shallow with depths less than 15 ft outside the natural channel through which the dredged channel is cut.

The waters of Old Tampa Bay (Figure XIV-1) are uniformly shallow with depths of less than 12 ft predominating. Depths of 15 to 17 ft are located near the center, while 18 to 24 ft can be found in a small area in the southeast corner of the bay. Water depths in Hillsborough Bay (Figure XIV-1) are also shallow with depths outside the dredged channel generally less than 12 ft.

One bridge crosses the channel at the entrance to Tampa Bay. Called the Sunshine Skyway, it is a land-filled causeway for most of its length, but becomes an 800-ft fixed span over the main ship channel with clearances of 149 ft at the center and 140 ft at the fenders (U.S. Department of Commerce, 1980). Originally constructed as a twin span bridge, it was reduced to a single span after the westward structure was downed when struck by a ship during a storm. No other bridges cross the ship channel. Three low-elevation causeway and bridge combinations cross Old Tampa Bay between Tampa and Pinellas Peninsula but do not cross the ship channel and, therefore, do not impact ship movement.

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\* See Notice to Mariners and latest editions of charts for controlling depths.

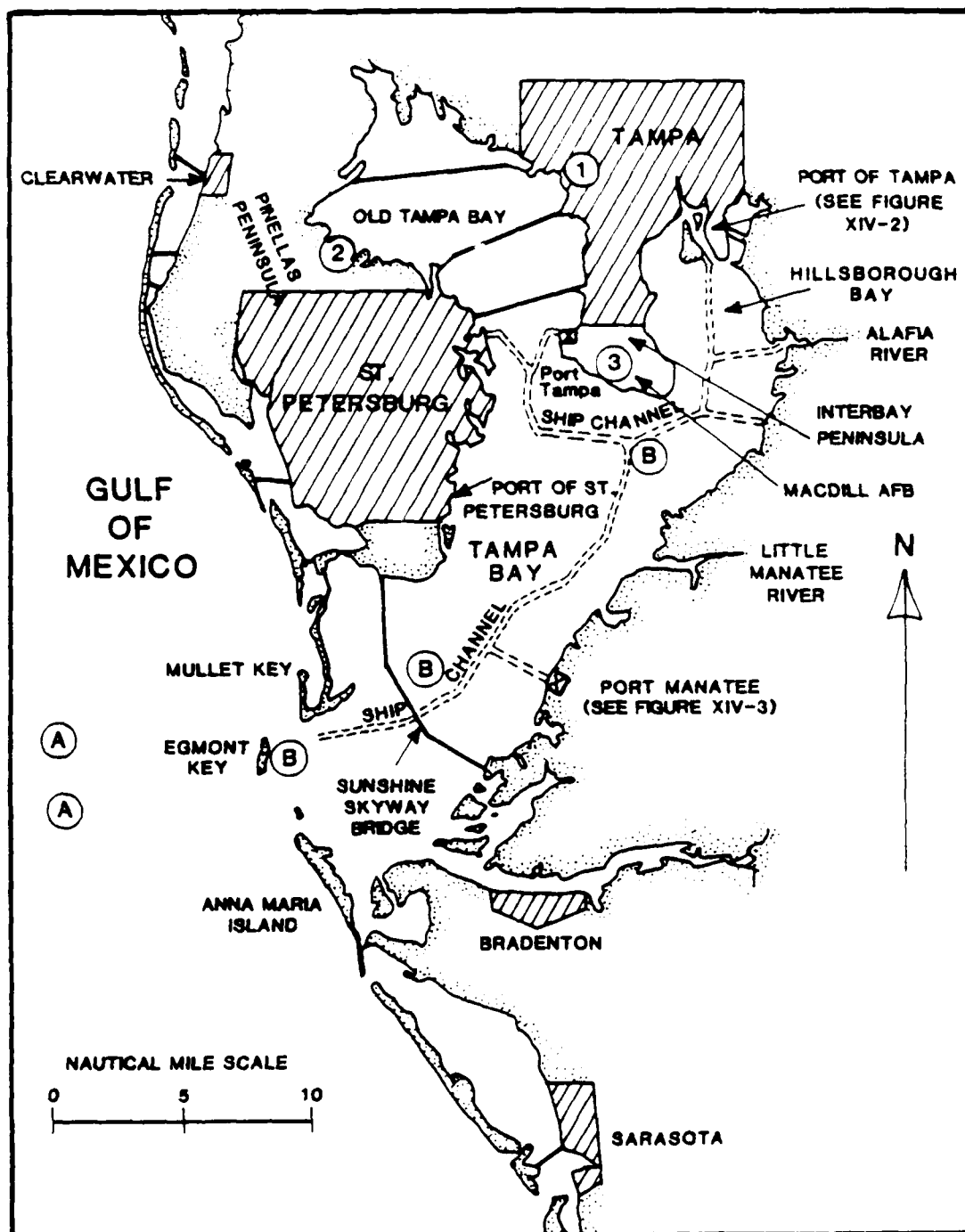


Figure XIV-1. Locations of Tampa Bay port facilities and area communities.

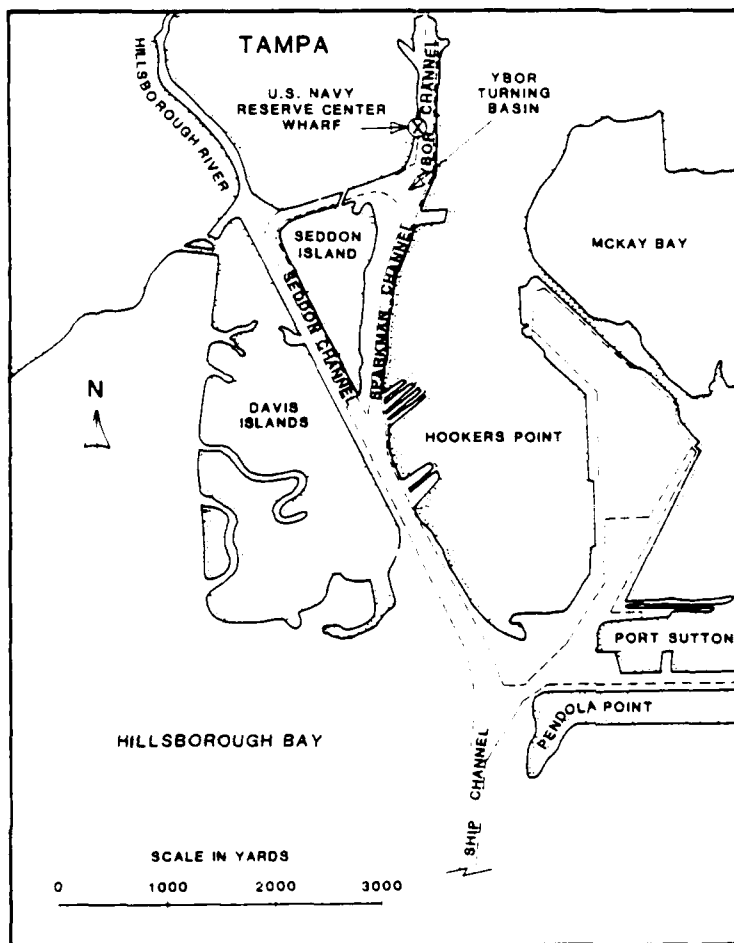


Figure XIV-2 Port of Tampa.

Two low-elevation, fixed, highway bridges cross the shallow waterway north of Davis Islands (Figure XIV-2). With a width of 34 ft and clearance of only 9 ft the bridges limit the use of the waterway to small craft. A railroad drawbridge with an unopened clearance of 5 ft crosses Garrison Channel north of Sedgon Island (Figure XIV-2) (U.S. Department of Commerce, 1980).

## 2. PORT AND HARBOR FACILITIES

### 2.1 BERTHS FOR DEEP DRAFT VESSELS

#### 2.1.1 Port of Tampa

The Port of Tampa includes the facilities at Tampa proper, Port Tampa, Port Sutton, and East Tampa (Alafia River). Of the 96 piers, wharves, and docks at the Port of Tampa, only 19 are owned by the Tampa Port Authority. Of these, 3 have alongside depths of less than 20 ft, and are not considered to be deep-draft facilities. The remaining 16 are located around the periphery of Hookers Point and on Ybor Channel. With alongside depths of 20 to 34 ft (30-34 ft predominating), the facilities have deck heights ranging from 6 to 15 ft, with most deck heights in the 6 to 8 ft range.

The U.S. Navy Reserve Center at Tampa maintains a wharf on the west side of Ybor Channel (Figure XIV-2). With an alongside depth of 23 ft and deck height of 9 ft, it has a usable berthing space of 380 ft.

Complete details of berthing facilities at the Port of Tampa can be found in Port Series No. 17, published in 1979 by the U.S. Army Corps of Engineers. The publication also provides details of 16 diesel-operated tugs and towboats, ranging from 300 to 3350 horsepower, used for docking and undocking vessels in Tampa Harbor, and towing to other points on the Gulf of Mexico.

#### 4.1.2 Port Manatee

Port Manatee, owned and operated by the Manatee County Port Authority, is located on the southeast side of Tampa Bay some 11 miles east of Egmont Key (Figure XIV-1).

Port Manatee is accessed by a privately dredged and maintained channel that intersects the main ship channel approximately 4 miles above Sunshine Skyway. Maintained at a depth of 40 ft, the 400-ft wide channel leads to a 35-ft deep 1500x600 ft turning basin (Figure XIV-3). The port has a 35-ft deep main basin 750 ft wide by 1500 ft long with five berths, each capable of accommodating a 750-ft ship. Alongside depths are 35 ft with deck heights of 6 to 8 ft. Each is equipped with 4 120-ton ballards, some 60-ton ballards, and 30-ton cleats. In addition, a barge berth capable of berthing barges to 600 ft long in 22 ft of water lies outside the main basin at the north side of the entrance (Manatee County Port Authority, 1981).

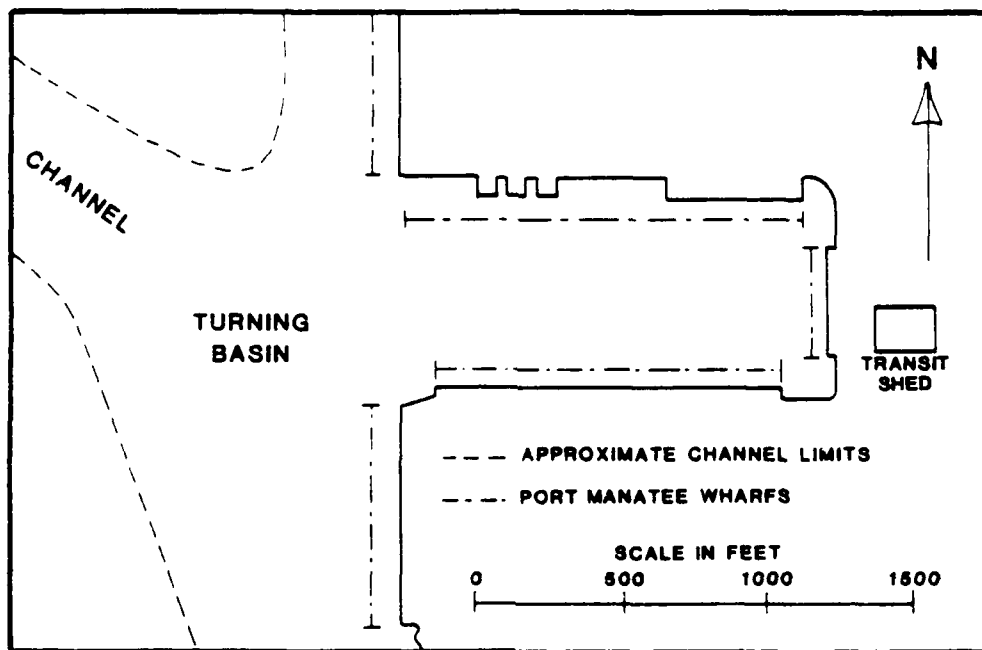


Figure XIV-3. Port Manatee.

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Port Manatee has two 2000 horsepower diesel-operated tugs available for docking, undocking, and vessel movement as necessary.

### 2.1.3 Port of St. Petersburg

The Port of St. Petersburg is not considered to be a true deep water port. Although, according to U.S. Department of Commerce, 1980, "A draft of 25 ft can be taken within 0.5 mile of St. Petersburg by following the main ship channel through the west reach leading to Port Tampa, then turning southwest into the natural deep water area extending toward St. Petersburg," the controlling depth in the port basin is only 15 ft. The Port of St. Petersburg has 1500 ft of berthing space with an alongside depth of 17 ft and a deck height of 8 ft (U.S. Department of Commerce, 1980).

The U.S. Coast Guard maintains two shallow-draft 210-ft cutters at the Port of St. Petersburg.

## 2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

Tampa Bay offers little shelter from heavy weather. The generally low elevations of the surrounding terrain afford only limited protection from strong winds. The configuration of the bay makes it most vulnerable to winds from the south or southwest, but the area is liable to the effects of wind from any direction.

Several anchorages are available in or near Tampa Bay. According to U.S. Department of Commerce, 1980, "Vessels with good ground tackle should anchor in the Tampa Anchorages, N and S of the Tampa Safety Fairway leading to Egmont Channel .... These anchorages can be used to ride out any gale short of a hurricane." The approximate positions of these anchorages are indicated by the letter "A" on Figure XIV-1. Other commonly used anchorages are indicated by the letter "B" on Figure XIV-1 but, according to local authorities, they are recommended as fair weather anchorages only and should not be used for riding out a storm.

Facilities are available for making repairs to hulls and machinery. Included in this capability are two graving docks, one measuring 900x150 ft (the largest on the Gulf Coast), and a second measuring 546x76 ft (Tampa Port Authority, 1981).

Tugs are normally used for assisting in docking, undocking, and towing. They are in plentiful supply for normal operations, but since some may be out of the area on towing jobs to other ports, and in view of likely increased demand when heavy weather is expected, arrangements for tug services should be made as early as possible.

## 2.3 FACILITIES FOR COASTAL AND IN-SHORE VESSELS

Tampa Bay is located in an important shipping and fishing area and serves many fishing vessels. The region is also a major winter resort area and home to thousands of recreational boaters, so Tampa Bay and surrounding waters are busy with small craft of many sizes and types.

Numerous marinas permeate the entire region, offering a complete range of accommodations and services, including repair, fuel, ice, water, and food for recreational boaters, and in some instances, small commercial fishing vessels. Several commercial facilities for serving coastal, inshore and fishing vessels are described in Port Series No. 17 published in 1979 by the U.S. Army Corps of Engineers.

## 3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT TAMPA

### 3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight may be gained into their typical behavior. This background knowledge and understanding allows attention to be focused on those storms most likely to have a serious effect on Tampa. However, the historical behavior of storms and their impact on Tampa should not be regarded as a reliable guide to the detailed behavior and impact of a particular storm as it approaches the port.

### 3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Tampa is considered to represent a threat to the port.

The location of Tampa on the west coast of the Florida Peninsula is significant, since the coastline is nearly parallel to normal tropical cyclone tracks as they move more or less northward out of the tropics. Also of importance is Tampa's latitude of about 27.8N; this is within the normal locus of tropical cyclone recurvature which oscillates between latitudes 25N and 35N. This latter factor is important, because it is the character of tropical cyclones to slow and intensify during the recurvature stage. During recurvature, it is difficult to predict with great accuracy the rate of recurvature, the storm speed of movement subsequent to recurvature and, obviously, the storm's precise future position at a point in time.

The hurricane season extends from late May through early November, but tropical cyclones occur occasionally outside of that period, with Tampa recording storms in February and December. During the 109-year period from 1871 through 1979 there were 171 tropical cyclones that met the 180 n mi threat

## TAMPA, FL

criteria for Tampa, an average of nearly 1.6 per year. Table XIV-1 shows the monthly totals and percentages. These data are graphically presented in Figure XIV-4.

Table XIV-1. Monthly totals of tropical cyclones passing within 180 n mi of Tampa during the period 1871-1979.

Month	Number	% of Total
February	1	0.5
May	4	2.4
June	21	12.3
July	12	7.0
August	28	16.4
September	50	29.3
October	52	30.4
November	2	1.2
December	1	0.5

Figure XIV-5 illustrates the 171 events as a function of compass octant from which tropical cyclones have approached Tampa during the years 1871-1979. The numbers in parentheses represent the percentage of cyclones from the sample approaching from a particular octant. The figure shows that the major threat sector extends from the southeast through southwest, as 67 percent of the cyclones approached from those sectors. It is significant to note that tropical cyclones have approached from all of the octants; no octant is "safe" from a storm's approach. Of the 12 tropical cyclones that have caused winds of gale force (34 kt or greater) to be recorded at Tampa since hourly wind records were first maintained in 1932, 5 have had trajectories that carried them over a large portion of the land mass southeast of Tampa.

Six tropical cyclones have formed within 180 n mi of Tampa, of which 2 developed rapidly to hurricane strength.

Records of tropical cyclones penetrating the 180 n mi critical area during the 81-year period for which tropical cyclone intensity data are available are tabulated in Table XIV-2 by intensity and month of occurrence. Whereas Table XIV-1 showed that October had a slightly higher percentage of tropical cyclone activity when all of the 171 tropical cyclones occurring during the period 1871-1979 were considered, Table XIV-2 shows September to be the month of greatest activity for the years 1899-1979. Of 53 hurricanes recorded during this period, 34 (64%) occurred in September and October. Overall, 79 out of 115 (69%) tropical cyclones occurring during this 81-year period were of the two strongest categories.



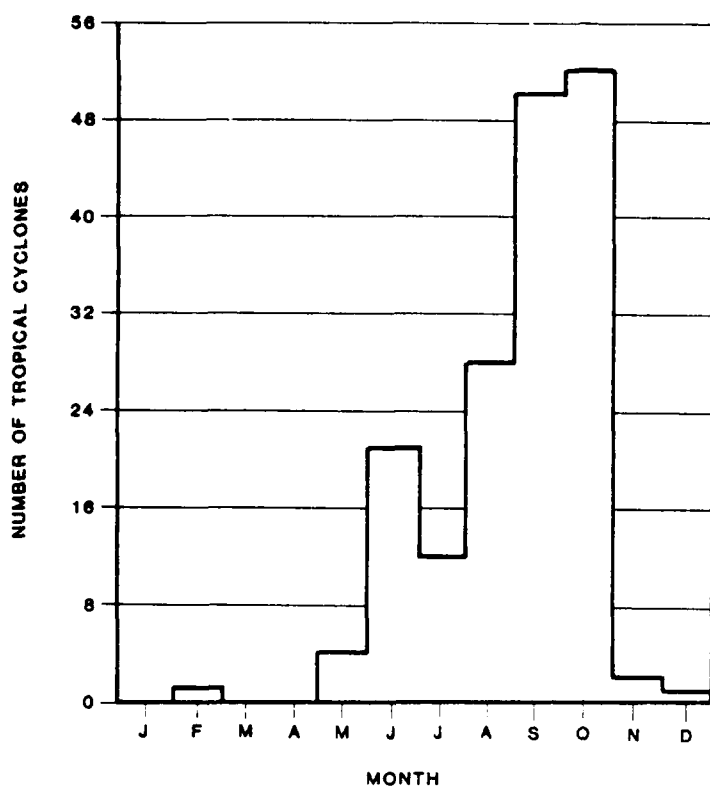
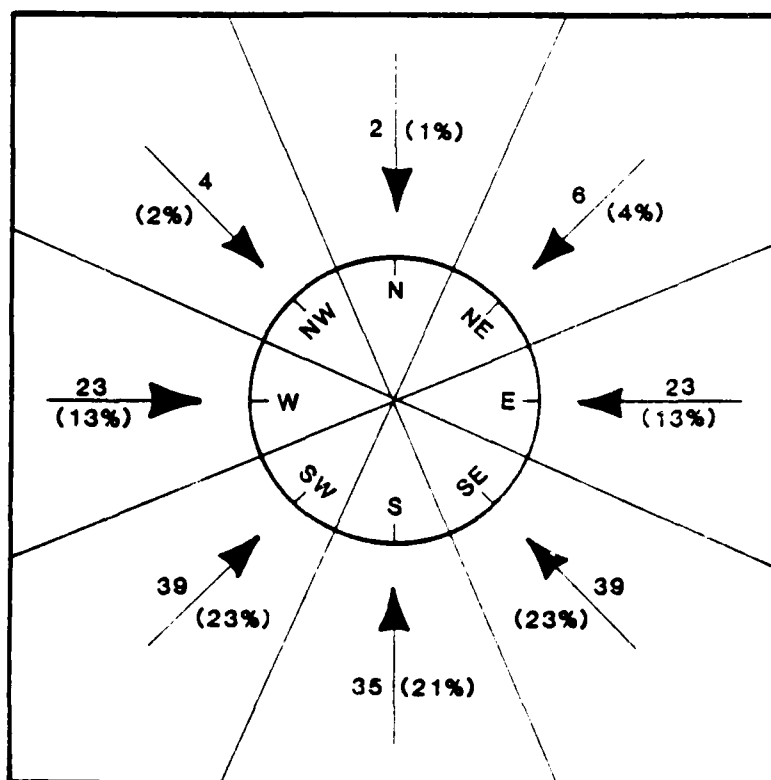


Figure XIV-4. Seasonal distribution of tropical cyclones passing within 180 n mi of Tampa (based on data from 1871-1979).

Figure XIV-5. Directions of approach of tropical cyclones that passed within 180 n mi of Tampa during the period 1871-1979. Numbers of storms approaching from each octant (e.g., 35) and percent of the total approaching from that octant (e.g., 21%) are shown.



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Table XIV-2. Classification of 115 tropical cyclones which passed within 180 n mi of Tampa during the period 1899-1979.

Maximum Intensity*	Feb-June	July	Aug	Sep	Oct	Nov-Dec	Totals
Hurricane	5	4	8	19	15	2	53
Intense Tropical Storm	3	1	6	6	5	0	26
Weak Tropical Storm	3	2	2	4	7	1	19
Tropical Depression	5	2	3	6	1	0	17
TOTALS	21	9	19	35	28	3	115

\*Intensity values reflect the maximum intensity while in the 180 n mi critical radius of Tampa. Upper limit of a weak tropical storm is 47 kt.

Figures XIV-6 through XIV-10 are statistical summaries of threat probability for the years 1871 through 1979. These summary data are presented in five charts, each representing data encompassing specific periods during the year: tropical cyclones occurring during February through June, July and August, September, October through December, and all tropical cyclones of record during the 109-year period.

The solid lines in these figures represent the "Percent Threat" for any storm location. The dashed lines represent approximate approach times to Tampa based on the climatological approach speed for a particular location. For example, in Figure XIV-6, a tropical cyclone located over western Cuba has an 80% probability of passing within 180 n mi of Tampa, and would reach Tampa in 36 to 48 hours (1 1/2-2 days).

The average speed of advance near Tampa of all tropical cyclones with winds of at least 34 kt that have threatened Tampa is about 8 kt. Early season (May to mid-July) speeds are somewhat higher, averaging 9 to 10 kt, while mid-season (mid-July to mid-August) speeds are about 7 kt (Neumann and Pryslak, 1981).

A comparison of Figures XIV-6 through XIV-9 shows some distinct differences in threat axis according to time of year. Early in the season, from February through June (Figure XIV-6), the primary threat axis originates in the western Caribbean Sea east of Nicaragua, and extends northward across western Cuba to Tampa. A secondary threat axis originates north of the eastern Bahama Islands and extends west-northwestward across Florida to Tampa.

By July and August (Figure XIV-7), the main threat axis has shifted dramatically northeastward to a position just south of the early season secondary track. Originating in the Lesser Antilles, an extension of the main

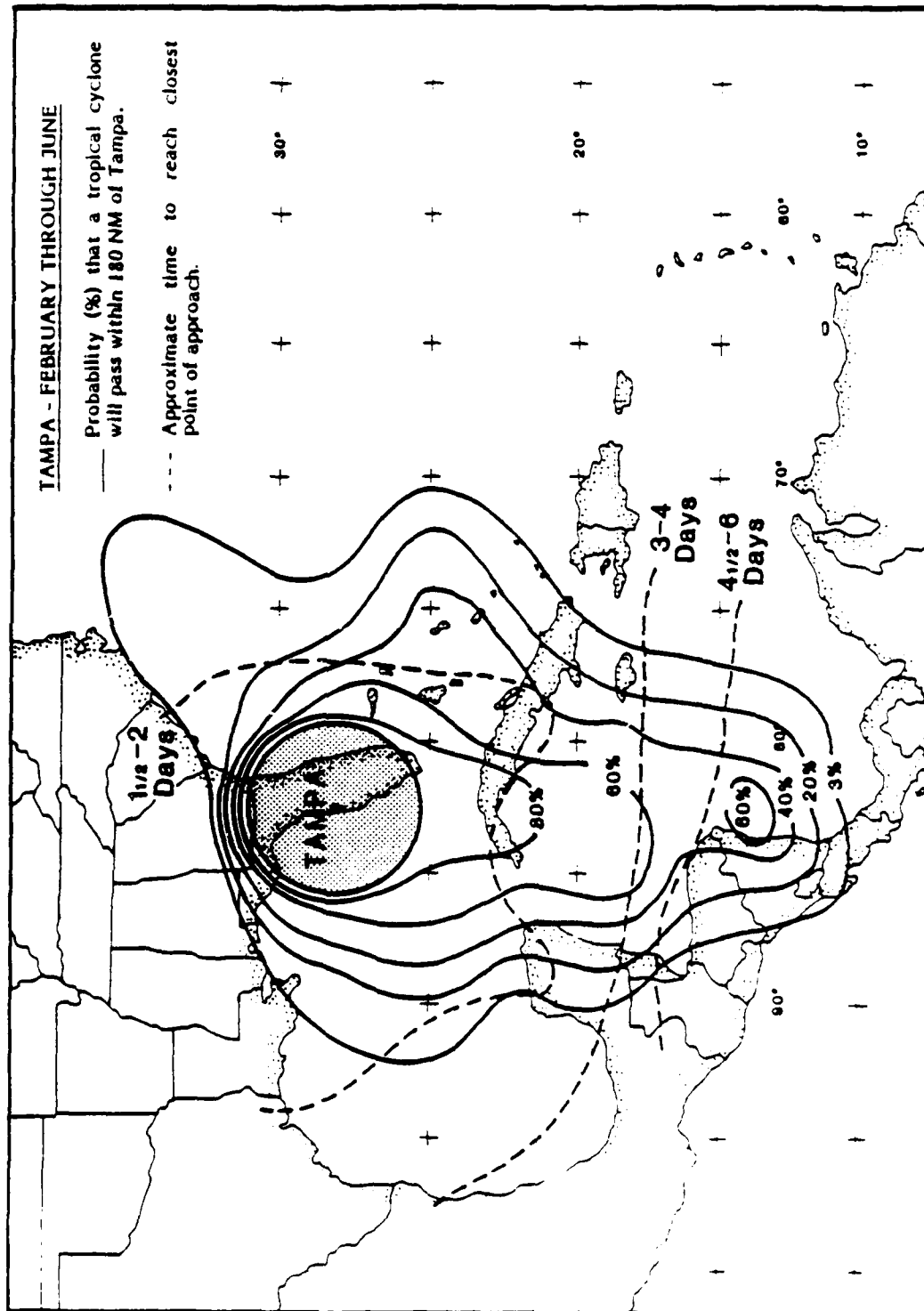


Figure XIV-6. Probability that a tropical cyclone will pass within 180 nm of Tampa (shaded circle), and approximate time to reach closest point of approach, during February through June (based on data from 1871-1979).

# TAMPA, FL

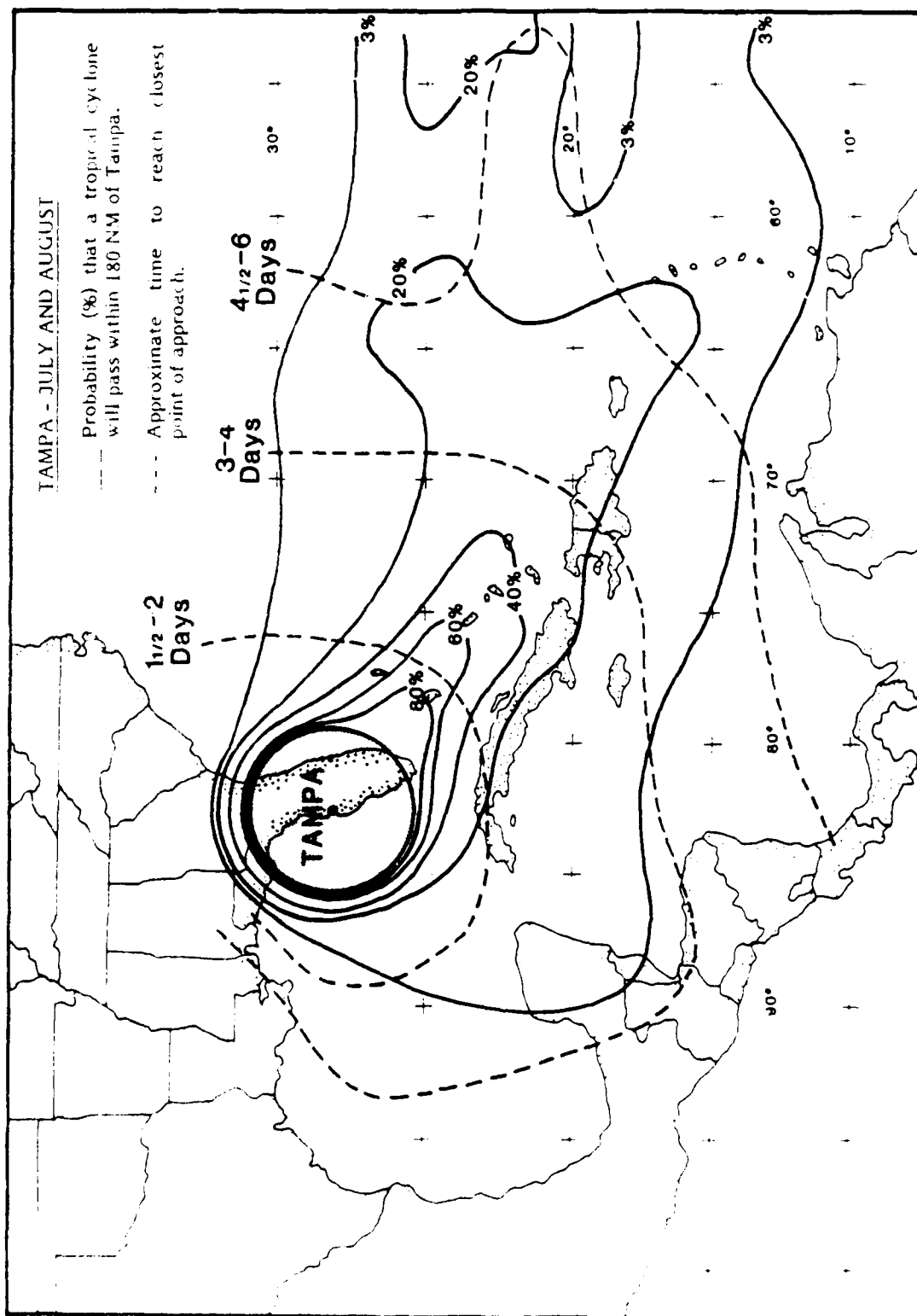


Figure XIV-7. Probability that a tropical cyclone will pass within 180 NM of Tampa (shaded circle), and approximate time to reach closest point of approach, during July and August (based on data from 1871-1979).

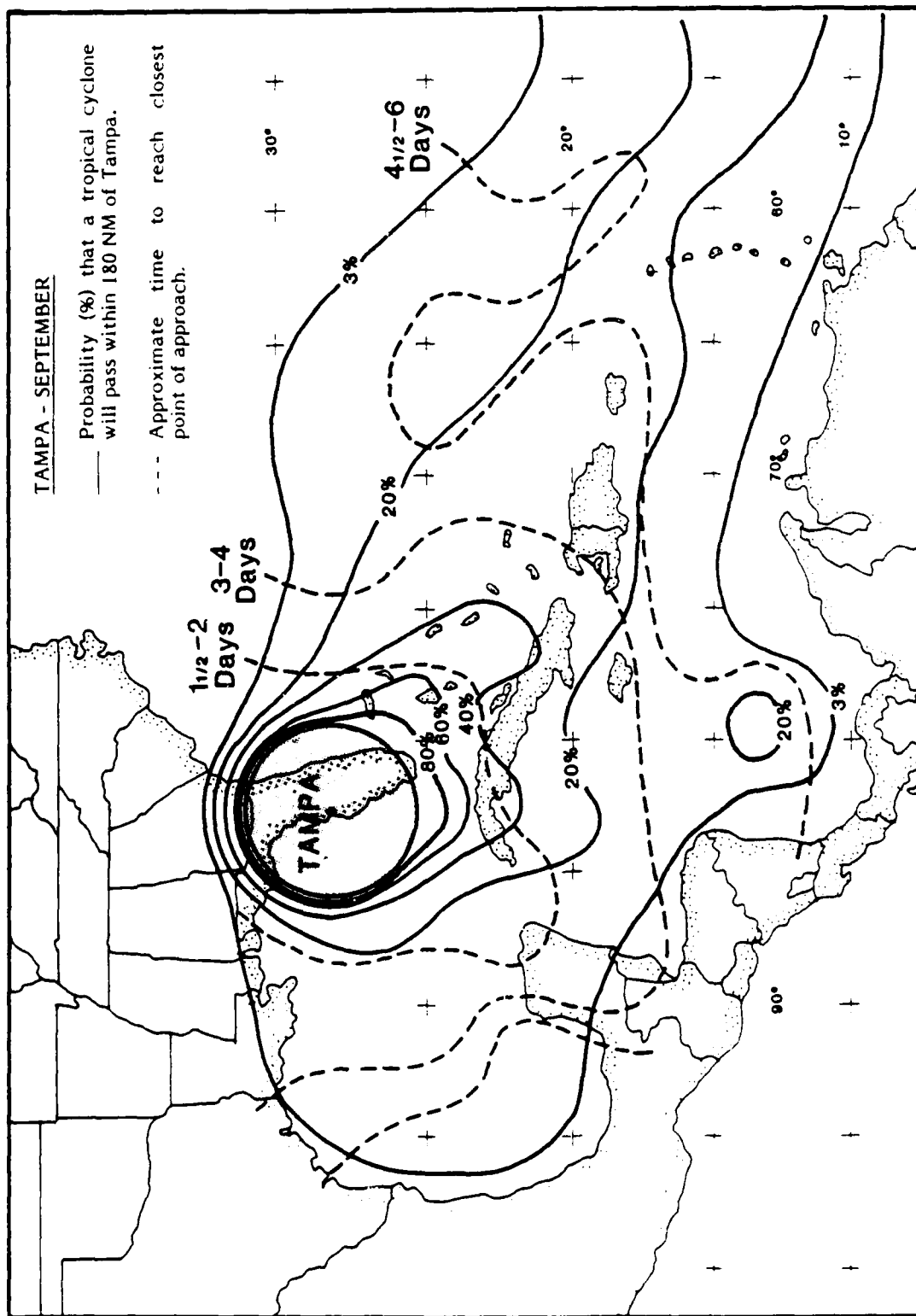


Figure XIV-8. Probability that a tropical cyclone will pass within 180 n mi of Tampa (snaded circle), and approximate time to reach closest point of approach, during September (based on data from 1871-1979).

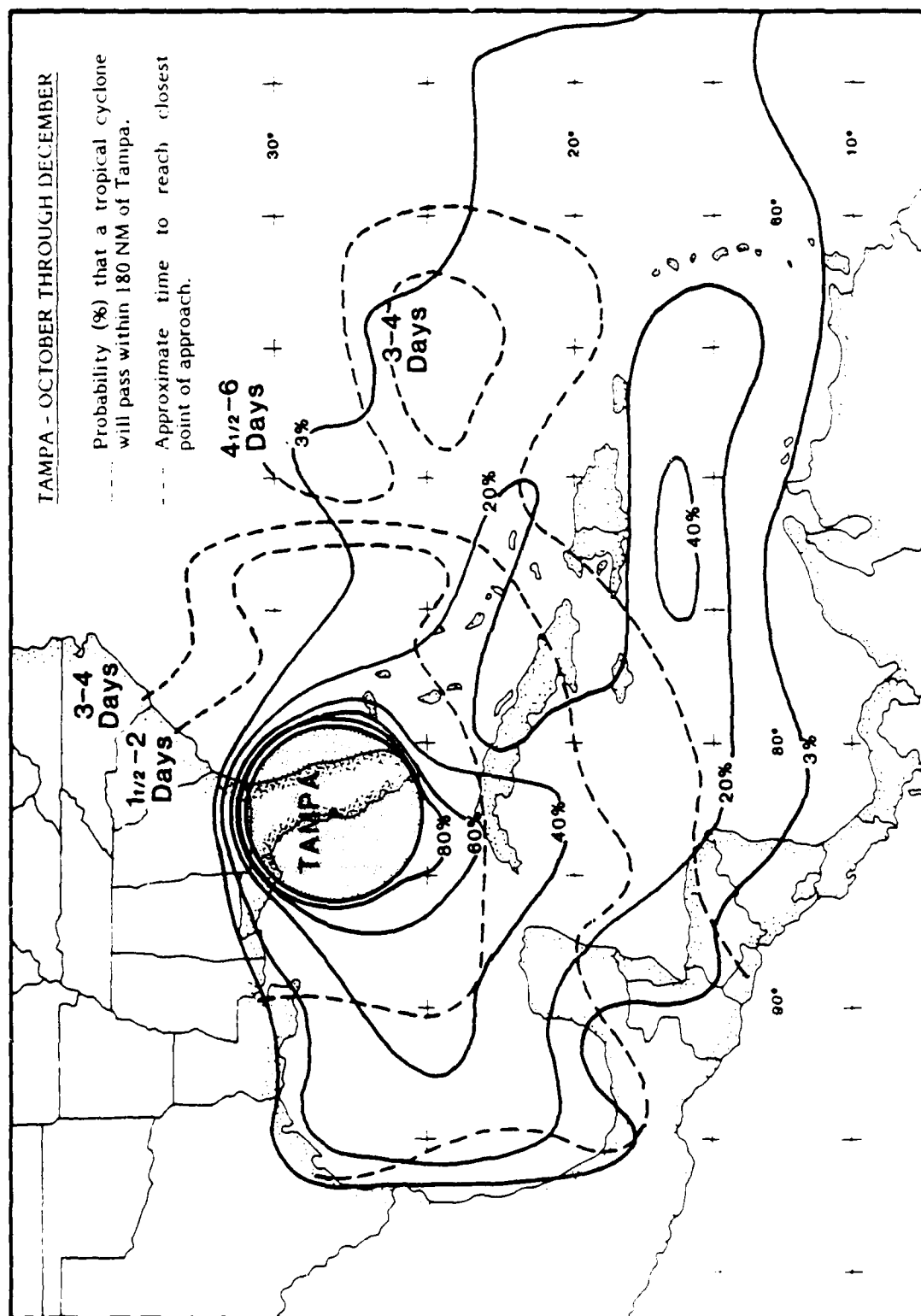


Figure XIV-9. Probability that a tropical cyclone will pass within 180 n mi of Tampa (shaded circle), and approximate time to reach closest point of approach, during October through December (based on data from 1871-1979).

track progresses northwestward across Puerto Rico, the Bahama Islands, and the Florida Peninsula to Tampa. A second extension of the same track originates in the Atlantic Ocean well east of the Bahama Islands and follows a westward course until it merges with the first axis near the Bahamas.

The main threat axis for September (Figure XIV-8) closely resembles one extension of the primary axis for July-August. Originating just north of the Lesser Antilles, it passes north of the Greater Antilles, over the Bahama Islands and the Florida Peninsula to Tampa. A secondary threat axis originates in the western Caribbean Sea and extends northward across Cuba to Tampa, bearing strong resemblance to the primary track for early season storms of February through June.

The threat analysis for October through December (Figure XIV-9) reveals a more complex pattern than that shown for other months, with three distinct tracks evident. The most prominent of the tracks originates near the Lesser Antilles and extends westward across the Caribbean Sea, then turns northward across western Cuba to Tampa. A second axis starts in the eastern Bahama Islands north of the Dominican Republic and extends west-northwestward along Florida to Tampa, while the third axis originates in the western Gulf of Campeche, and extends northeastward across the Gulf of Mexico to Tampa.

Figure XIV-10 represents a composite picture of threat probability and time to CPA curves for the entire year and is derived from all tropical cyclone tracks passing within 180 n mi of Tampa during the period 1871-1979.

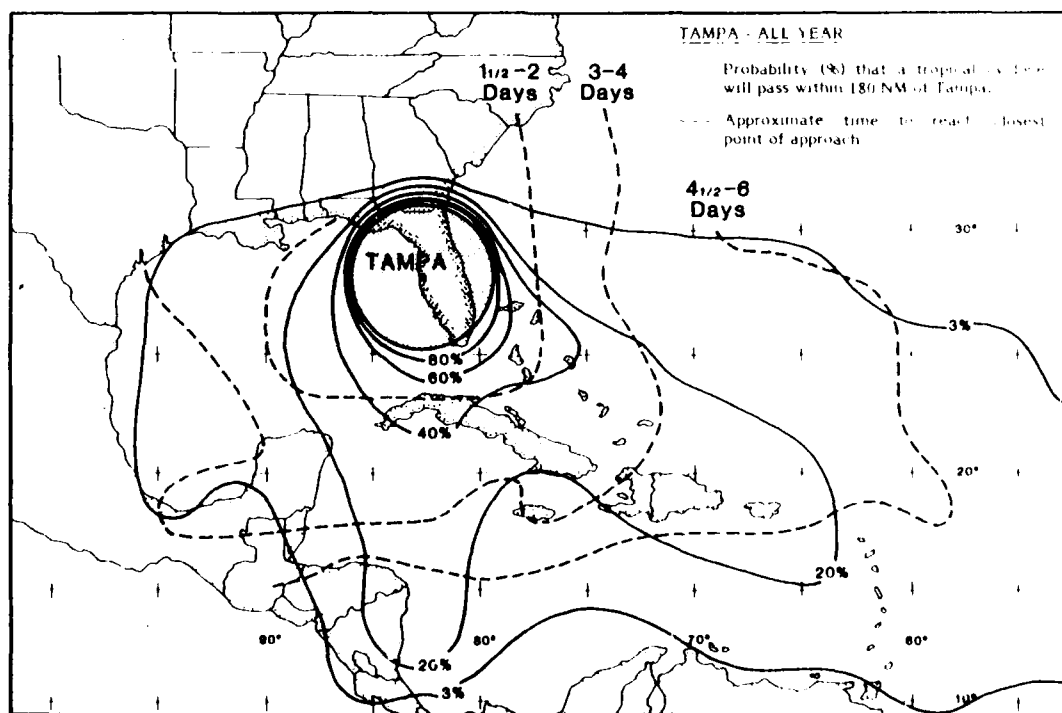


Figure XIV-10. Probability and CPA curves for all tropical cyclones passing within 180 n mi of Tampa (shaded circle), based on data from 1871-1979

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### 3.3 WIND AND TOPOGRAPHICAL EFFECTS

Records of hourly wind data for locations in the greater Tampa Bay area are available for the period 1932 through 1979. One location -- St. Petersburg -- has records available for the entire 48-year period, while Tampa and MacDill Air Force Base have records for shorter periods. The hourly records that were used in this study are:

Tampa	November 1935 through September 1979
St. Petersburg	August 1932 through September 1979
MacDill AFB	September 1941 through September 1979

The locations of the observing stations for Tampa, St. Petersburg, and MacDill AFB are indicated by the numbers "1" through "3" respectively on Figure XIV-1.

In the 48-year period for which wind data are available, 75 tropical cyclones approached within 180 n mi of Tampa, an average of 1.6 per year. A tabular breakdown based on intensity of these cyclones while within the 180 n mi radius is shown in Table XIV-3.

Table XIV-3. Classification of the 75 tropical cyclones which passed within 180 n mi of Tampa during the period 1932-1979.

Hurricane ( 63 kt)	Tropical Storm (34 to 63 kt)	Tropical Depression ( 34 kt)	Total (No.)
31	28	16	75

Of the 59 tropical storms and hurricanes, 12 caused sustained winds of 34 kt or greater in the Tampa area, based solely on hourly wind observations during the period. Four of the 12 caused sustained winds of 50 kt or greater, with 1 causing sustained winds of hurricane force (64 kt or greater). Two of the remaining 3 caused gusts to hurricane force. Based on the 1932 through 1979 wind data, gale force winds can be expected from 1 out of every 5 tropical storms/hurricanes passing within 180 n mi of Tampa, and hurricane force winds can be expected from 1 out of every 20 tropical storms/hurricanes.

Figure XIV-11 depicts the tracks of all 12 storms that caused gale force winds in the Tampa area (track information from Neumann et al., 1978). Figure XIV-12 shows the location of each storm center when winds of 23 kt or greater and 34 kt or greater were recorded. Figure XIV-13 depicts the wind direction distribution for the same 12 storms while winds of gale force were recorded. It is interesting to note that while gale force winds were recorded from all directions, 11 of the 12 gale force occurrences started when the wind direction fell within very narrow boundaries -- from north-northeast through northeast, and from south-southwest through southwest.



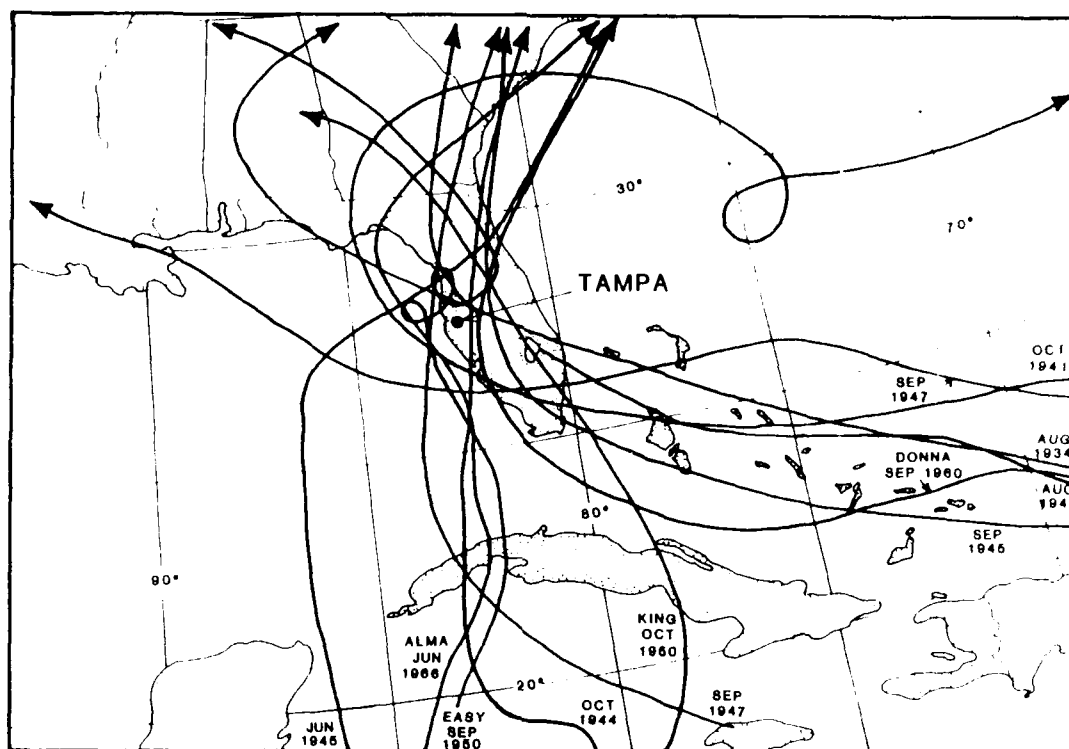


Figure XIV-11. Tracks of the 12 tropical cyclones 1939-79 that caused sustained winds of 34 kt or greater at Tampa. Although wind records have been kept since 1932, no gale force winds were recorded until 1939.

In terms of vulnerability of the Port of Tampa to wind damage, wind from a south or southwesterly direction would have the most potential for destruction because Tampa Bay is open in those directions. Although the terrain around the bay is low in elevation, wind speed would be reduced, if only slightly, for directions other than south or southwest. Buildings at or near the port would provide more protection from northerly winds than winds from other directions.

### 3.4 WAVE ACTION ON TAMPA BAY AND HILLSBOROUGH BAY

Except for a small opening at its mouth, Tampa Bay is well protected from ocean wave activity. The openings, located between Edmont Key and Passage Key, which lies north of Anna Maria Island (Figure XIV-11), is about 1 1/2 miles wide with water depths of 20-25 ft. Large ocean waves moving in an approximate 060° direction could move through this narrow passage and into Tampa Bay, but most of the wave energy would be lost due to shallow water and angular spreading on the east side of the passage. However, high winds resulting from the passage of tropical cyclones present a wind wave hazard to marine facilities around the bay.

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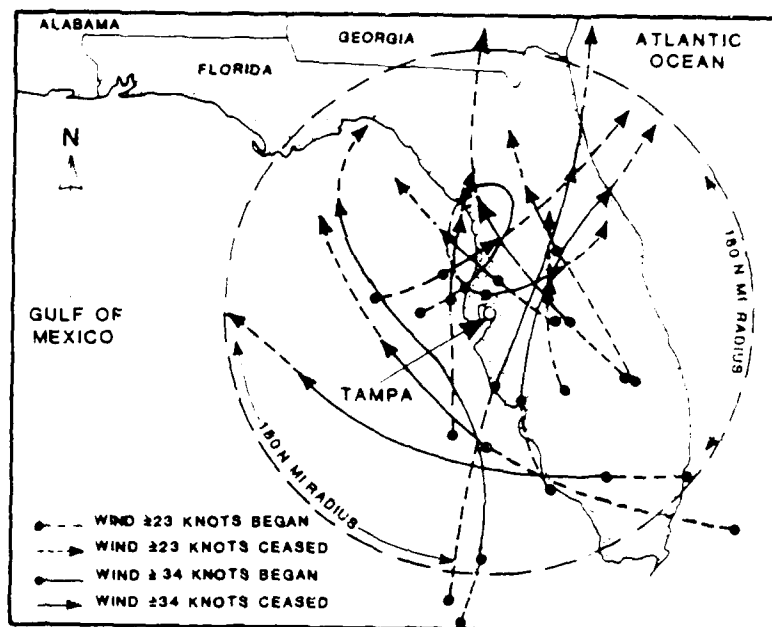
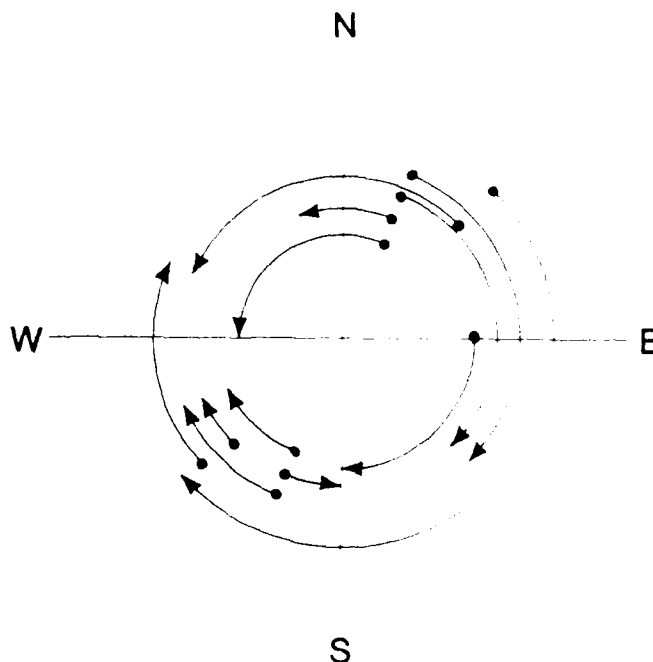


Figure XIV-12. Track segments of 1939-79 tropical cyclones that produced winds 34 kt or greater (solid lines) at Tampa. Also shown are track segments of winds 23 kt or greater (dashed lines).

Figure XIV-13. Directions of winds 34 kt or greater in the Tampa area during tropical cyclone passages 1939-79. Beginning and end of gale force winds shown by dot and arrowhead, respectively, as in Figure XIV-12. Clockwise direction changes indicate storm passage to the west, while counterclockwise changes indicate passages to the east.



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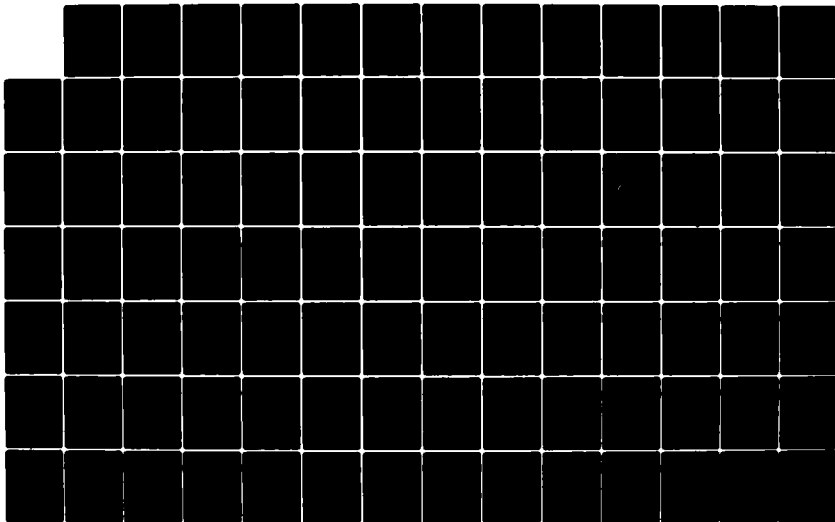
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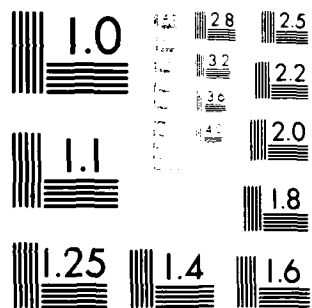
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Maximum wind wave action on Tampa Bay would result from strong north-easterly or southwesterly winds. Using an average water depth of 20 ft and a fetch length of 20 miles, the following calculations can be made: 35 kt winds would generate 4 ft wind waves; 50 kt winds, 5.3 ft wind waves; 75 kt winds, 6.5 ft wind waves; and 85 kt winds, 7 ft wind waves (U.S. Army Corps of Engineers, 1973). Adding a tidal surge height of 10 ft would increase the 85 kt wind waves to slightly over 9 ft.

It should be noted that wind wave calculations are based on a uniform depth over an assumed flat bottom. Since water depth in Tampa Bay and Hillsborough Bay varies greatly from one location to another, the above calculations and those to follow are for use as a guide only and should not be regarded as absolute values.

#### 3.4.1 Facilities on Tampa Bay

Port Tampa is located on the west side of Interbay Peninsula (Figure XIV-1). Open to the west, reduced water depths and fetch length limit wind wave heights to 4 ft for 85 kt winds. The Port of St. Petersburg (Figure XIV-1) is exposed to east and southeast winds and waves. With a fetch length of 7 miles, and water depths averaging 15 ft, the following wave calculations can be made: 35 kt winds, 3 ft wind waves; 50 kt winds, 4 ft wind waves; 75 kt winds, 5 ft wind waves; and 85 kt winds, 5.6 ft wind waves. A 10 ft tidal surge would increase the 85 kt wind wave height to 7.5 ft (U.S. Army Corps of Engineers, 1973).

Port Manatee (Figures XIV-1 and XIV-3) is exposed to the west, but is well protected from significant normal wave action by a spoil bank some 700 yards west of the Port Manatee turning basin, and by water depths of only 3 ft (outside the channel cut) extending approximately 800 yards offshore. If a tidal surge were to increase water levels by 10 ft, the port would be exposed to wave heights as follows: 35 kt winds, 3 ft wind waves; 50 kt winds, 4 ft wind waves; 75 kt winds, 5 ft wind waves; and 85 kt winds, 5.5 ft wind waves (U.S. Army Corps of Engineers, 1973).

#### 3.4.2 Facilities on Hillsborough Bay

The shape of Hillsborough Bay (Figure XIV-1) renders it most susceptible to wind waves generated by south and southwesterly winds. With a north-south length of about 8 miles and an average water depth of 15 ft, sustained 35 kt winds from the south may produce waves of about 3 ft. Similarly, 50 kt winds would produce 4 ft wind waves; 75 kt winds, 5.3 ft wind waves, and 85 kt winds, 5.8 ft wind waves. If a storm surge of 10 ft were added to the water depth, the wind waves for a 35 kt wind would increase to 3.8 ft; 50 kt winds, 5.2 ft wind waves; 75 kt winds, 7 ft wind waves; and 85 kt winds, 7.7 ft wind waves (U.S. Army Corps of Engineers, 1973). Most of the Hillsborough Bay deep-draft

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facilities are protected from wave action by Davis Islands, Seddon Island, Hookers Point and Pendola Point (Figure XIV-2). Port Sutton is exposed to the west, but limited fetch length and water depth preclude significant wave action from that direction. East Tampa (Alafia River) is also exposed to westerly winds and waves. With a maximum fetch length of about 3.5 miles, the maximum wind wave height generated by an 85-kt wind would be on the order of 5.5 ft.

### 3.5 STORM SURGE AND TIDES

Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles to the right of its path. The dome height is related to local pressure (i.e., a barometer effect dependent on the intensity of the storm) and to local winds. Other significant contributing factors are storm speed, direction of approach, bottom topography, and coincidence with astronomical tide.

The worst circumstances (Harris, 1963, Pore and Barrientos, 1976, and Tampa Bay Regional Planning Council, 1981) would include:

- (1) An intense storm approaching perpendicular to the coast with the harbor within 30 n mi to the right of the storm's track.
- (2) Broad, shallow, slowly shoaling bathymetry.
- (3) Coincidence with high astronomical tide.

The waters along the west coast of the Florida Peninsula in the vicinity of Tampa Bay meet the bathymetry criteria. This factor, coupled with the characteristics of Tampa Bay (i.e., large mouth exposed to seaward and shallow depths), render Tampa Bay exceptionally vulnerable to storm surges.

Documents on file at the National Weather Service Office in Ruskin, Florida indicate that the Tampa Bay area has recorded storm surges as early as 1848. Some excerpts from the records are given in Table XIV-4

Figure XIV-14 shows the tracks of the storms causing the water level changes listed in Table XIV-4 for the years 1910 through 1972. (Track information from Neumann et al., 1978, and DeAngelis, 1973.) Tracks for the 1848 storms are unavailable.

The values given in Table XIV-4 show that a tidal surge of 5 ft or more is not an uncommon occurrence in Tampa Bay, and that surges of devastating proportions (such as the one in 1848) are possible. Also of significance is the record for October 18, 1910 when the water level in Hillsborough River fell 9 ft below MLW. This circumstance was caused by a tropical cyclone of tropical storm intensity passing to the east of Tampa while on a northward course, causing offshore winds that forced much of the water from the bay, resulting in the water level drop. The same effect was observed when Hurricane Betsy passed well south of Tampa on a westward course in 1965. According to local authorities "about a mile of shoreline" was exposed when Betsy passed.

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Table XIV-4. Water Level data for Tampa Bay and adjacent waters during near passages of tropical cyclones as extracted from records maintained by the National Weather Service Office, Ruskin, FL.\*

Date	Water Level Data
1848 Sep 25	Tide 15' **
1848 Oct 16	Tide 10' **
1910 Oct 18	Water 9' <u>below</u> MLW in Hillsborough River - usual depression 1'.
1921 Oct 25*	Tide 10.5' ** highest since 1848
1935 Sep 2-4	Tide 5.3' above MLW
1944 Oct 18-19	Tide 3.1' above MLW
1945 Jun 24	Tide 5.2' above MLW
1950 Sep 3-6	Tide 6.5' above MLW
1966 Jun 8-9	Tide 4.5' **
1972 Jun 18-19	Tide 5.6' above MSL

\*Height for October 25, 1921 was measured at the "local office of United States Engineers" at the waterfront of Tampa on Hillsborough Bay. The specific locations of other measurement sites were not recorded.

\*\*Zero reference not specified.

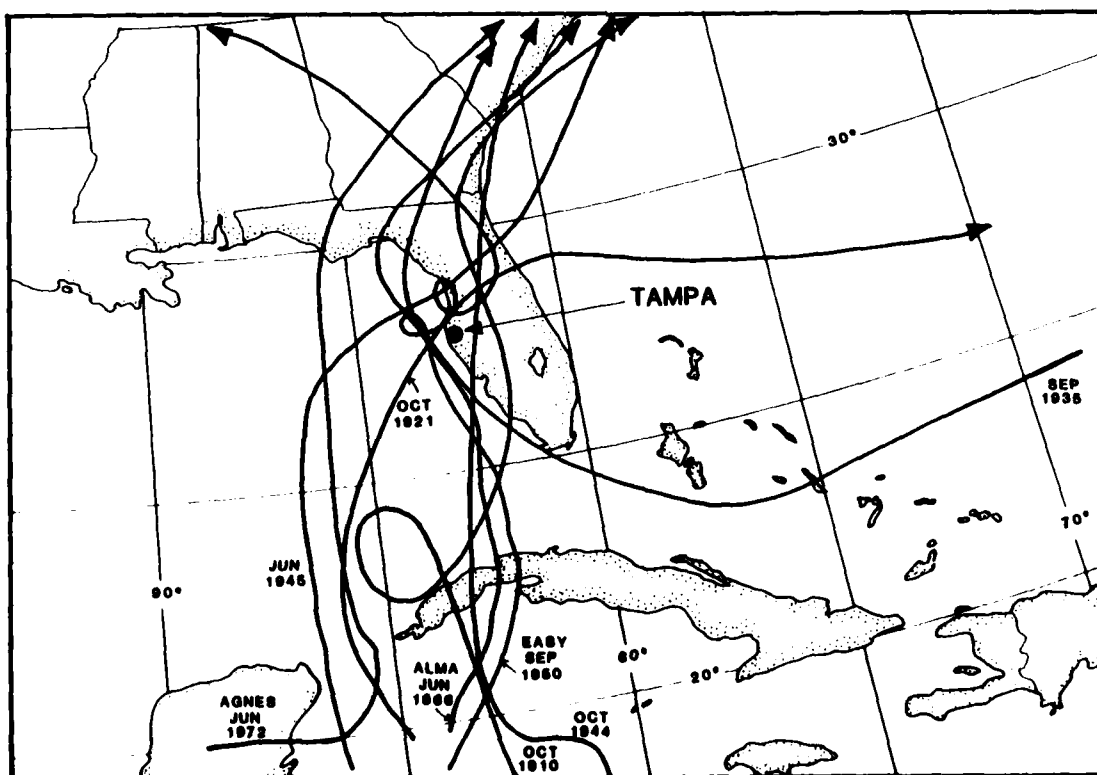


Figure XIV-14. Tracks of tropical cyclones that caused significant changes in water levels in Tampa Bay during the years 1910-72.

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Wind records during the passage of Betsy show that the Tampa Bay region experienced winds in the 20 to 30 kt range with gusts about 10 kt higher. The winds had a strong offshore component for about 72 hours -- a duration factor that contributed heavily to the water level drop.

An excellent example of the susceptibility of Tampa Bay to water level rises occurred on June 18, 1982, when a small, subtropical low pressure center moved northward along the west coast of the Florida Peninsula. Tampa Airport (location #1 on Figure XIV-1) recorded gusts to 39 kt, while maximum sustained winds observed along the coast were near minimal gale velocity. Despite these relatively low wind velocities, water rises of 4 to 5 ft were recorded in Tampa Bay. Local authorities express the opinion that, if the wind had not ceased an hour before the time of high astronomical tide, the water rise would have been higher.

Recent advances in storm surge prediction techniques have led to the development of an improved storm surge forecasting tool. Developed by the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service, it is called SLOSH and estimates the Sea, Lake, and Overland Surges from Hurricanes (Jelesnianski and Chen, 1979 and Tampa Bay Regional Planning Council, 1981). Tampa Bay values were computed for 3600 grid points on a "telescoping" polar grid system. The level of resolution varies from one grid square representing approximately 1.6 square miles on the coast to 0.6 square miles inland. Several storm tracks were evaluated, comprising 4 directions of travel with 3 to 8 parallel tracks for each direction. Five storm intensities were used, each corresponding to a category on the "Saffir/Simpson Scale," which was developed by Herbert Saffir and Dr. Robert H. Simpson. Table XIV-5 outlines the Saffir/Simpson scale.

Table XIV-5. Saffir/Simpson scale.

<u>Scale Number</u>	<u>Central Pressure</u>		<u>Wind</u>		<u>Damage</u>
	<u>Millibars</u>	<u>Inches</u>	<u>MPH</u>	<u>Knots</u>	
1	> 980	> 28.94	74-95	64-83	Minimal
2	965-979	28.50-28.91	96-110	84-95	Moderate
3	945-964	27.91-28.47	111-130	96-113	Extensive
4	920-944	27.17-27.88	131-155	114-135	Extreme
5	<920	<27.17	155+	135+	Catastrophic



## TAMPA, FL

Data printouts for several computer runs of the SLOSH model were reviewed, and surge height calculations for 11 selected points in Tampa Bay were extracted for 18 storm tracks. These values are given in Table XIV-6. Saffir/Simpson categories 1, 3 and 5 are given where available, otherwise only category 3 is given. Figure XIV-15 depicts specific storm tracks used for the SLOSH model calculations while Figure XIV-16 shows each of the selected locations for which data was extracted.

A review of the values given in Table XIV-6 reveals that the surge heights for locations in the upper reaches of Tampa Bay, especially in the main port area in Hillsborough Bay, are significantly higher than those near the mouth of the bay. The highest water levels would result from category 5 storms moving inland just north of the main portion of Tampa Bay -- tracks LST, LTC and LCL.

Water levels resulting from what is essentially a "worst case" storm (such as a category 5 storm following track LTC), would inundate all of the Interbay Peninsula (Figure XIV-16), Davis Islands, Seddon Island, Hookers Point (Figure XIV-2), and the land area around greater Tampa Bay to a distance of as much as 4 miles inland in some areas.

Also of significance is the effect that westward tracking storms such as ET or EN would have on water levels. In both cases, a category 3 storm would cause water rises of near 10 ft in Hillsborough Bay, which would inundate Davis Islands, Seddon Island, Hookers Point and about 50 percent of the Interbay Peninsula, including most of MacDill AFB.

Astronomical tides in Tampa Bay are semi-diurnal with a range of about 2.3 ft. According to U.S. Coast Pilot 5, 1980 published by the U.S. Department of Commerce, "A strong offshore wind sometimes lowers the water surface at Tampa and in the dredged channels as much as 4 ft, and retards the time of high water by as much as 3 hours. A continued SW wind raises the water by nearly the same amount and advances the time of high water by as much as 1 hour."

Tidal currents of 3 kt or more at the strength of the greater ebb of the day may occur in Egmont Channel, Passage Key Inlet, and off Port Tampa, but flood velocities seldom exceed 2 kt. The tidal currents are greatly affected by winds. A clockwise rotary tidal current with considerable daily variation is observed 6.7 miles west of Egmont Key Light (U.S. Department of Commerce, 1980).

# TAMPA, FL

Table XIV-6. SLOSH surge height calculations for selected locations in Tampa Bay. All heights in feet above MSL.<sup>1</sup>

Track <sup>2</sup>	Saffir/Simpson Scale Number	Location <sup>3</sup>										
		1	2	3	4	5	6	7	8	9	10	11
LNN	1	3.5	2.4	4.3	3.5	5.2	4.8	3.8	3.2	3.3	3.0	4.1
	3	6.5	7.8	8.3	9.7	10.4	8.9	6.9	6.0	6.0	5.8	7.5
	5	6.3	10.0	8.1	9.4	10.2	8.7	6.7	5.7	5.7	5.5	7.3
LNP	1	4.0	3.1	4.9	5.7	6.2	5.5	4.3	3.6	3.6	3.4	4.7
	3	7.7	8.9	9.7	11.7	12.5	10.8	8.3	7.0	7.0	6.9	9.1
	5	7.4	10.9	9.7	11.2	12.1	10.4	7.9	6.9	6.8	6.7	8.7
LTN	1	4.3	4.1	5.5	6.6	7.2	6.4	4.8	3.8	3.9	3.7	5.2
	3	8.7	9.5	11.0	13.8	15.1	13.0	9.4	8.1	7.7	7.8	10.3
	5	9.9	11.7	13.0	15.7	17.0	14.5	10.5	8.9	8.5	8.6	11.5
LCL	1	4.6	4.7	5.8	7.2	8.1	7.2	5.2	3.9	3.8	3.6	5.6
	3	9.8	9.7	11.9	16.2	17.8	15.2	10.7	8.9	8.0	8.4	11.8
	5	11.4	13.2	15.1	18.7	21.0	17.5	12.2	9.9	8.8	9.8	13.4
LTC	1	4.6	2.3	5.5	7.1	8.1	7.3	5.3	3.9	3.5	3.4	5.7
	3	10.2	9.3	11.6	16.7	18.7	16.4	11.1	9.3	7.2	8.4	12.4
	5	13.3	12.1	16.0	22.8	25.7	22.6	14.9	11.4	8.4	10.8	16.6
LST	1	4.0	1.0	4.5	5.8	6.7	6.7	4.8	3.6	3.3	3.1	5.1
	3	8.2	7.0	8.8	13.8	15.7	14.8	9.8	8.7	6.4	7.2	10.7
	5	12.8	11.1	14.3	22.2	25.2	23.4	14.2	11.6	7.9	9.9	15.8
LKE	1	2.4	1.0	2.4	1.9	4.2	4.4	3.2	2.8	2.2	2.1	3.3
	3	4.3	1.0	4.2	7.3	8.2	8.6	6.3	6.0	3.5	3.9	6.2
	5	4.8	1.0	3.5	7.5	9.7	10.2	8.8	9.9	3.7	5.4	7.1
LTS	1	1.3	1.0	1.0	1.0	1.9	2.4	2.0	1.9	1.5	1.5	1.7
	3	1.5	1.0	1.1	1.0	3.5	3.9	3.0	3.2	2.3	1.9	2.4
	5	1.6	1.0	1.0	1.0	2.4	3.2	2.8	4.9	2.7	2.4	1.7
N30	3	5.0	5.8	5.5	6.7	6.7	6.0	4.9	4.5	5.0	4.6	5.3
N15	3	5.6	7.8	6.9	9.0	9.1	7.9	5.5	5.4	6.0	5.4	6.3
N00	3	5.1	6.6	6.4	9.3	9.6	8.1	5.3	4.7	5.1	4.4	6.1
P30	3	3.6	1.5	4.0	2.7	4.8	4.3	3.5	3.1	3.5	3.2	3.8
P15	3	4.1	3.9	4.9	6.0	6.4	5.5	4.1	3.6	4.7	3.9	4.6
P00	3	4.4	5.2	5.4	8.5	8.1	6.6	4.5	4.1	4.5	4.4	5.1
ET	3	4.4	5.1	4.9	10.1	9.7	6.5	3.9	3.6	2.9	3.6	4.4
EN	3	5.5	7.7	6.3	11.3	9.4	6.5	4.8	4.5	3.9	4.3	5.3
EC	3	3.8	3.0	4.3	2.3	4.5	4.0	3.1	4.0	3.2	3.2	3.7
ES	3	1.3	1.0	1.0	1.0	1.4	1.4	1.2	1.4	1.9	1.5	1.2

<sup>1</sup>SLOSH values are estimated to be within plus or minus 15% of observed water levels. Values do not consider wave set-up, rainfall, or astronomical tidal effects (Tampa Bay Regional Planning Council, 1981).

<sup>2</sup>Track codes are keyed to Figure XIV-15.

<sup>3</sup>Location numbers correspond to locations listed below and are keyed to Figure XIV-16.

1 Port of St. Petersburg; 2 Safety Harbor (Upper Old Tampa Bay); 3 Port Tampa; 4 Upper Hillsborough Bay; 5 McKay Bay; 6 Alafia River; 7 Little Manatee River; 8 Port Manatee; 9-11 Anchorages

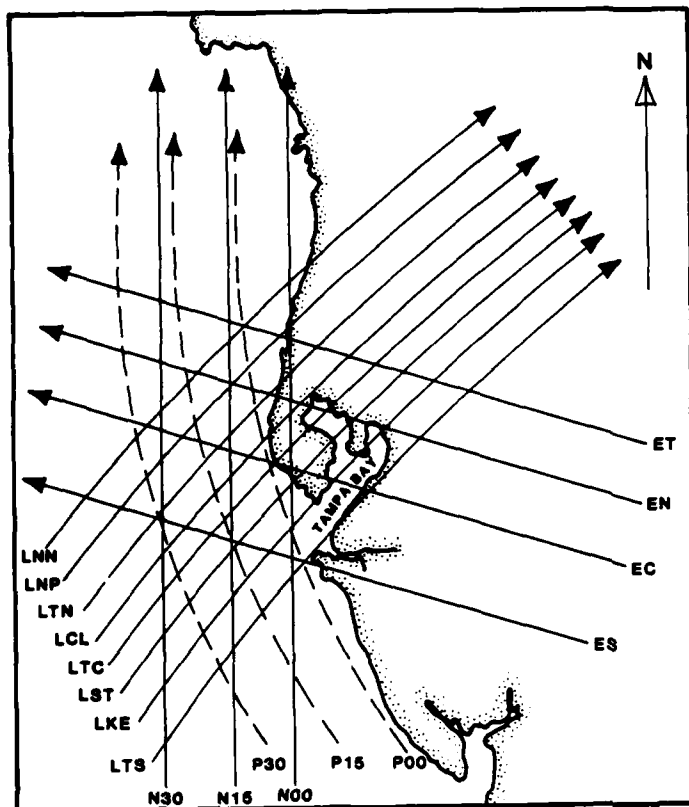
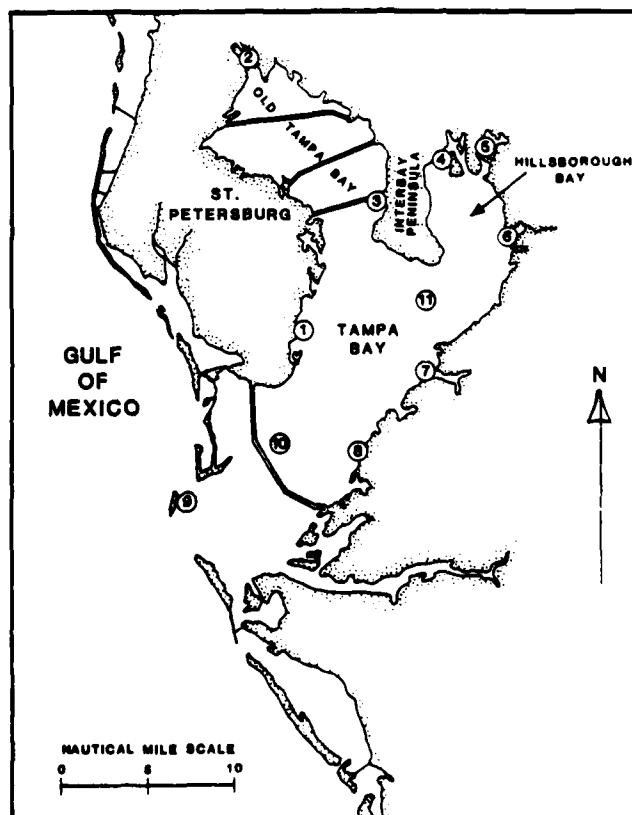


Figure XIV-15. Selected tracks of hurricanes simulated by SLOSH numerical storm surge model for Tampa Bay. (Tampa Bay Regional Planning Council, 1981.)

Figure XIV-16. SLOSH numerical storm surge locations listed in Table XIV-6.



## TAMPA, FL

### 4. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for hurricane preparedness at the U.S. Naval Reserve Center at Tampa are addressed in COMSEABASWINGSLANT COMNAVBASE JAX OPORD 2000. MacDill AFB is governed by MacDill OPLAN 355.1. The Tampa Port Authority promulgates its Hurricane Preparedness Plan as Section 14 of the Port of Tampa Operations Manual.

#### 4.1 THREAT ASSESSMENT

A review of the tropical cyclone threat analysis presented in Section 3 of this evaluation indicates that Tampa Bay is at considerable risk to damage resulting primarily from tropical cyclone storm surge, but also from high wind. The absence of sheltered berths or anchorages makes evasion at sea the safest course of action for all seaworthy deep-draft vessels as soon as it can be established that a particular tropical cyclone poses a threat to Tampa Bay. Early assessment of each potential threat is essential, and should be related to the setting of hurricane conditions of readiness by military and civil authorities, and conducted using current advisories and forecasts issued by the Navy and National Weather Service, as well as climatology as presented herein.

As can be seen in Figures XIV-6 through XIV-11 and Figure XIV-14, the greatest threats to Tampa are posed by tropical cyclones moving northward out of the western Caribbean Sea, or westward out of the Atlantic Ocean just north of the Greater Antilles, and which approach Tampa from the southeast, south, or southwest. A greater threat of storm surge occurs when a tropical cyclone approaches Tampa from the southwest quadrant, and makes landfall within 100 miles north of Tampa Bay. A storm making landfall south of Tampa Bay such that strong winds with a significant offshore component would cross Tampa Bay would be expected to cause a significant lowering of the Tampa Bay water level.

The individual storm intensity and speed of movement will affect the extent of damage which can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that Tampa is located in the dangerous right front quadrant of the storm can result in severe wind and storm surge conditions. It must be remembered, however, that Tampa is vulnerable to storms from the east as well as the west, and a westerly moving storm crossing the Florida Peninsula can cause significant damage in the Tampa vicinity. The months of maximum threat in terms of frequency are September and October. Of those storms causing sustained winds of 34 kt or greater to be recorded in the Tampa area (Figure XIV-11), sixty-seven percent (8 of 12) occurred in September or October; but the 4 storms that caused sustained winds of 50 kt or greater occurred in the separate months of June, August, September and October.

#### 4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy deep-draft vessels when Tampa is under threat from an intense tropical storm (48 kt or greater) or hurricane (64 kt or greater) approaching from the Gulf of Mexico and forecast to make landfall within 100 n mi of Tampa, or threatened by a hurricane approaching the Tampa area from the south or southeast across the Florida Peninsula. Timing of the decision to evade is affected by:

- (1) The forward speed of the tropical cyclone.
- (2) The radius of hazardous winds and seas that can impact on a vessel's capability to reach open water and then maneuver to evade.
- (3) The elapsed time to make preparation to get underway.
- (4) The elapsed time to reach open water.

For example:

A worst case situation would be an intense tropical cyclone moving toward Tampa Bay from the southwest (similar to track LTC in Figure XIV-15). Assume 6 hours are required to make preparations to get underway after the decision to evade at sea is made. Approximately 3 to 4 hours are required to transit the channels leading to the open sea. A tropical cyclone approaching at an average speed of 10 kt will have moved 100 miles closer to Tampa Bay by the time sea room is attained. Add to this the radius from the tropical cyclone center of strong winds likely to hamper port operations, say 200 n mi. Summing these values gives 300 miles (200 +100) or 30 hours as the minimum tropical cyclone displacement from Tampa in distance or time when the decision must be made to evade at sea successfully. A greater margin may be applicable depending on greater cyclone speed and intensity, and ship speed capability.

Hurricane Condition III is set when hurricane force winds are possible within 48 hours. It is apparent that the decision to prepare for sortie should be made soon after setting Hurricane Condition III. Although at this time the storm center may be more than 500 miles distant, it should be remembered that the average tropical cyclone forecast error over a 48-hour period is on the order of 210 n mi for those tropical cyclones threatening Tampa (Neumann and Pelissier, 1981). Departures coincident with the setting of Condition III are considered to be the wise and safest course of action. Later departures than this wager the accuracy of information on the storm's behavior against mounting risks of heavy weather damage. It is pertinent to note that the U.S. Coast Guard advises that all ships in good condition should put to sea upon the setting of Hurricane Condition III.

## TAMPA, FL

Once sea room is attained upon departure from Tampa, the tactics employed will depend on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement. Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information with today's satellite technology is accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity, and movement.

Ship masters with access to these advisories/warnings are in the best possible position to modify evasion routes and tactics to successfully evade the storm. The cardinal rule of seamanship is to avoid the dangerous right-hand semicircle. The following guidelines are offered.

(1) For tropical cyclones approaching from the west or northwest: After an early departure to escape worst effects of head winds and seas, steam south or southeast along the coast until clear of the storm.

(2) For tropical cyclones approaching from the south or southwest: Tropical cyclones approaching from these directions pose the most perplexing of evasion problems due to the possibility of storm track changes to the west or northwest. If a vessel were capable of making a reasonable SOA, say 15 kt, and could depart sufficiently early so as to take advantage of following winds and seas, yet avoid the hazardous conditions close to the main portion of the storm, one option would be to steam west or northwest. Once sufficient maneuvering room was attained clear of the storm, a course change to the south or southwest may then be made to bring the vessel to a latitude south of the storm center. Short of this course of action, few options remain. In no case should a vessel be placed in the position of being "trapped" between a tropical cyclone and the Florida coastline north of Tampa. An evasion route may have to be altered based on unexpected changes in cyclone movement. Evasion tactics must be based on the latest tropical cyclone forecast position and movement.

(3) For tropical cyclones approaching from the east or southeast (across the Florida Peninsula): Steam west-southwestward until sufficient maneuvering room is attained, then southward until reaching a latitude south of the storm center.

### 4.3 RETURNING TO PORT

The damage and disarray at a port resulting from a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Harbor facilities may be so damaged as to preclude offering even minimal services. Check with the Port Authority before attempting to return.

#### 4.4 ASSUMING A "WAIT AND SEE" POSTURE AT ANCHOR

A marginal threat may dictate a "wait and see" posture as a reasonable course of action to follow. A marginal threat situation would include those situations where an intense tropical storm or hurricane is a considerable distance away from Tampa and not likely to cause severe conditions at Tampa within 48 hours (a pre-Condition III situation but still potentially threatening), or situations where the storm is meandering with no established direction of movement. As was mentioned in Section 2.2, the Tampa Anchorages located north and south of the Tampa Safety Fairway leading to Egmont Key can be used to ride out any gale short of a hurricane. Leaving the pier for anchorage to await later developments in storm intensity and/or movement offers the advantage of decreasing the time required to reach open sea should evasion at sea become necessary.

#### 4.5 REMAINING AT TAMPA

Remaining in port at Tampa is an option that should receive serious consideration in secondary threat situations or in those instances when a vessel is incapable of successful evasion at sea. Secondary threat situations include:

- (1) A tropical cyclone developing within the 180 n mi radius critical area.
- (2) A weak tropical cyclone (maximum winds less than 48 kt) approaching Tampa and forecast not to intensify.
- (3) A tropical cyclone with winds greater than 47 kt forecast to pass more than 100 miles from Tampa and the forecast 50 kt wind radius does not encompass Tampa.

If the decision is to remain in port at Tampa, the following recommendation are offered:

(1) Since SLOSH storm surge calculations (Table XIV-6) show that Port Manatee has significantly lower storm surge heights than those calculated for the main Port of Tampa facility in upper Hillsborough Bay, and the facilities at Port Manatee are of new construction, Port Manatee would be the preferred port facility in which to ride out a tropical cyclone at Tampa. Local port officials indicate that many shallow draft vessels that cannot put to sea, such as dredges and barges that work in Tampa Bay, usually use Port Manatee during tropical cyclone threat situations. For this reason, dock space may be limited, and early arrangements for accommodations are desirable.

(2) If space at Port Manatee is not available or it is not feasible to use Port Manatee for other reasons, utilization of the main Port of Tampa facility in upper Hillsborough Bay is suggested.

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Little protection from wind is offered in either of the above situations. It is recommended that in each case, vessels be ballasted down as much as possible, and secured to the dock with sufficient lines to withstand predicted wind forces, yet allow water height fluctuations of the predicted amounts.

Should a master choose to remain in port it should be borne in mind that his vessel will be exposed to dangers beyond that of wind and storm surge. Other vessels may be broken loose from their moorings, and become floating hazards. Also, the danger is ever present that a damaged or sunken vessel could effectively block the narrow ship channels in the bay, thereby trapping shipping in the port for some time after a storm has passed.

### 5. ADVICE TO SHALLOW DRAFT VESSELS

Shallow draft vessels should, if feasible, be removed from the water and firmly secured ashore at an elevation of at least 20 ft (30 ft if the storm is posing a "worst case" threat) to avoid possible high water. Short of this, small craft should seek shelter in the Hillsborough River, Alafia River, or Little Manatee River.

Table XIV-7 lists channel depths and bridge data for the lower reaches of the rivers. If a drawbridge clearance is indicated, that clearance will most likely prevail in a storm threat situation, as draw bridges are left in the down position to facilitate evacuation of area residents.

Table XIV-7. River channel and bridge data for the Hillsborough, Alafia and Little Manatee Rivers (U.S. Department of Commerce, 1980).

River	Controlling Depth	Bridge	
		Clearance	Miles Above Bay
Hillsborough	4.5 ft <sup>1</sup>	40 ft	0.1
		35 ft	3.2
		10 ft <sup>2</sup>	4.3
		7 ft <sup>2</sup>	6.0
Alafia	3.0 ft <sup>4</sup>	28 ft <sup>3</sup>	1.0
		6 ft	1.1
Little Manatee	3.0 ft	12 ft	2.3 <sup>5</sup>

1 - Maintained to 2.5 miles above mouth. Depths above 2.5 mile point are not specified.

2 - Draw bridge

3 - Swing bridge

4 - With local knowledge at high water

5 - Height of adjacent railroad span not specified.



## TAMPA, FL

Seeking shelter at berths or marinas around the periphery of Tampa Bay is not recommended because of the potential for storm surge, and using open anchorages in Tampa Bay to ride out a tropical cyclone would be extremely hazardous. Virtually no protection is afforded except near the lee shore, and even then it is minimal. Wind wave activity can be quite destructive, not to mention the hazards of floating debris resulting from the effects of wind waves, high water, and high winds.

The following extract from U.S. Coast Pilot 5, Atlantic Ocean: Gulf of Mexico, Puerto Rico, and Virgin Islands, as published by the U.S. Department of Commerce in 1980 is relevant:

"Hurricane Moorings. On receiving advisory notice of a tropical disturbance small boats should seek shelter in a small winding stream whose banks are lined with trees, preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of the trees will act as fenders and the branches having more give than the trunks, will ease the shocks of the heavy gusts. If the banks are lined only with small trees or large shrubs, use clumps of them within each hawser loop. Keep clear of any tall pines as they generally have shallow roots and are apt to be blown down."

The prudent small boat operator will have selected several potential havens beforehand in which to take shelter in various tropical cyclone threat situations. He will proceed to his haven well in advance to avoid the chaos and congestion endured by his fellow boaters who delay until the onset of destructive conditions is imminent.

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## XV. BOSTON, MASSACHUSETTS

### SUMMARY

This study concludes that the inner harbor of Boston is a hurricane haven. This conclusion is based on the following factors:

(1) New England is not in the primary hurricane belt, and hurricane force winds associated with tropical cyclones are uncommon in the Boston area.

(3) The terrain surrounding the river-type harbor provides protection from wind and wave action.

Historically the tropical cyclones that have caused widespread damage in the area have tracked northward at high speeds (>30 kt). The normal track is northeastward at somewhat lower speeds. These major threat events are associated with a particular circulation pattern with two key features: a deep tropospheric trough over the eastern United States, and a much stronger than normal high pressure system off the east coast. This circulation pattern is not common during the peak hurricane season (September).

The high speed (>30 kt) northward movement of tropical cyclones under this type of circulation pattern creates a dual problem for vessels that sortie. First, there is minimum time available to clear the harbor and shoal areas; and second, the high speed cyclone is difficult to outrun once at sea.

Tropical cyclones that make landfall south of Long Island and approach Boston Harbor from overland are not considered a hazard to seagoing vessels. Storms of this type can create flooding problems.

The outer portions of the harbor (anchorage 1 and seaward) and the outer harbor anchorage areas are not considered haven areas. The outer harbor is generally unprotected from winds and seas, particularly those from an easterly direction. The anchorage areas do not have exceptional holding, they are restricted in size, and there are numerous shoals and ledges throughout the outer harbor area.

This hurricane haven evaluation was prepared by  
R.E. Englebretson and J.D. Jarrell of Science  
Applications, Inc. (SAI), Monterey, CA 93940.

## BOSTON, MA

### 1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Boston, the largest city and harbor in the New England region, is located on the western shore of Massachusetts Bay about 40 n mi west-northwest of the northern tip of Cape Cod (Figure XV-1). The City of Boston and its surrounding area are generally hilly, with maximum elevations of approximately 500 ft reached within 10 statute miles of the main harbor. The surrounding terrain, peninsulas and islands provide some protection to the harbor area, except for cases where the winds are from the east. There are numerous dangers in the approaches to the harbor: islands, shoals and rocks extend 3-4 n mi from shore through all approaches.

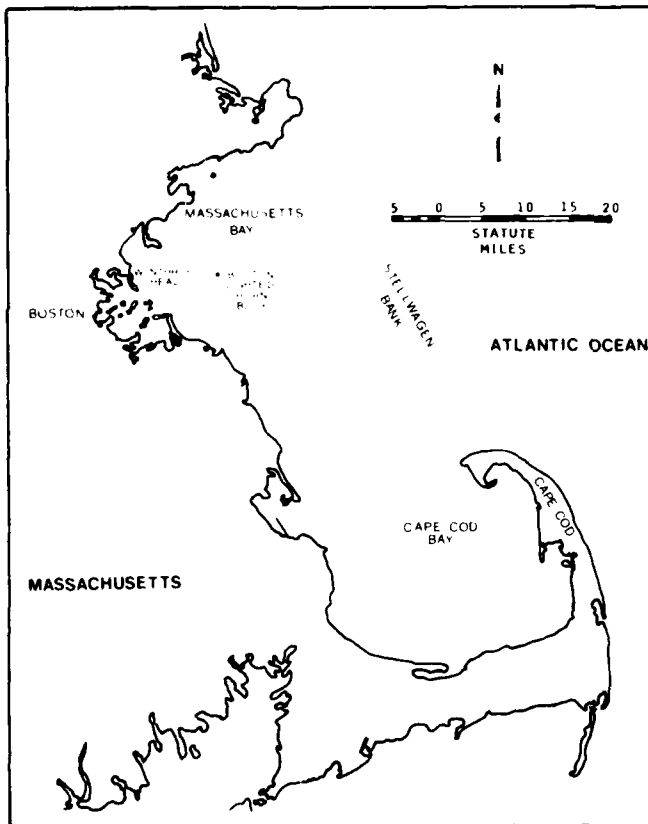


Figure XV-1. Locator map of the Boston and Cape Cod region.

Several outstanding landmarks mark the various approaches to the main Boston Harbor area. A tall red, white, and blue standpipe on Winthrop Head is conspicuous when approaching from the northeastward. The most prominent island in the entrance as viewed from easterly approaches is Great Brewster. A turreted tower on Point Allerton is markedly visible when approaching from the south. Two illuminated radio towers are located two miles south of Point Allerton; these are useful for night approaches.

## 2. THE HARBOR, APPROACHES AND FACILITIES

The harbor includes all the tidewater area lying within a line from the southern extremity of Deer Island to Point Allerton, about 4 n mi to the south-eastward (see Figure XV-2). Important tributaries that flow into and form part of the main harbor are the Charles, Chelsea and Mystic Rivers. The harbor region extends to the south of the main harbor and Boston proper, where the Weymouth Fore River and Dorchester and Hingham Bays comprise the more important harbor areas.

### 2.1 APPROACHES

A buoyed Traffic Separation Scheme has been established in the approach to Boston Harbor (see charts 13270, 13267; 13246, 13260 and 13200). The inbound and outbound traffic lanes are 2 n mi wide and extend about 125 n mi east-southeast to seaward from the precautionary area. The precautionary area has a radius of 5 n mi centered on the Boston Lighted Horn Buoy B ( $42^{\circ}22'42''N$ ,  $70^{\circ}47'00''W$ ), which is about 7.8 n mi east-northeastward of Deer Island.

The principal entrance for deep-draft vessels from the precautionary area to Boston Harbor is via Boston North Channel to President Roads to Boston Main Channel (see charts 13270 and 13272). Because of the numerous islands, shoals and rocks, extreme caution should be used in approaching Boston Harbor.

According to Coast Pilot 1, when approaching Boston from the Cape Cod sector, soundings of 20 fathoms or more ensure a distance of 5 n mi from the shore and a position well outside of outlying rocks. Inside the 20 fathom contour, the soundings are very irregular and cannot be depended upon as a rule to keep a vessel out of danger. Deep-draft vessels should use the Boston Traffic Separation Scheme route for approaching Boston Harbor.

When making an approach in fog, a course should be laid to clear the Boston Lighted Horn Buoy B and the water should not be shoaled to less than 20 fathoms until the buoy is positively located. The Boston North Channel, Boston South Channel, and the Narrows Channel are the main entrances from the sea to President Roads. Several other channels of less importance are used by local vessels.

### 2.2 ANCHORAGES

General, explosives, and special anchorages of Boston Harbor are shown on chart 13272. The most commonly used general-purpose anchorage is on the north side of President Roads. The anchorage in Nantasket Roads, westward of the southern entrance to the Narrows, has depths up to 50 ft. The anchorage on the westerly side of Georges Island provides some shelter from easterly winds and

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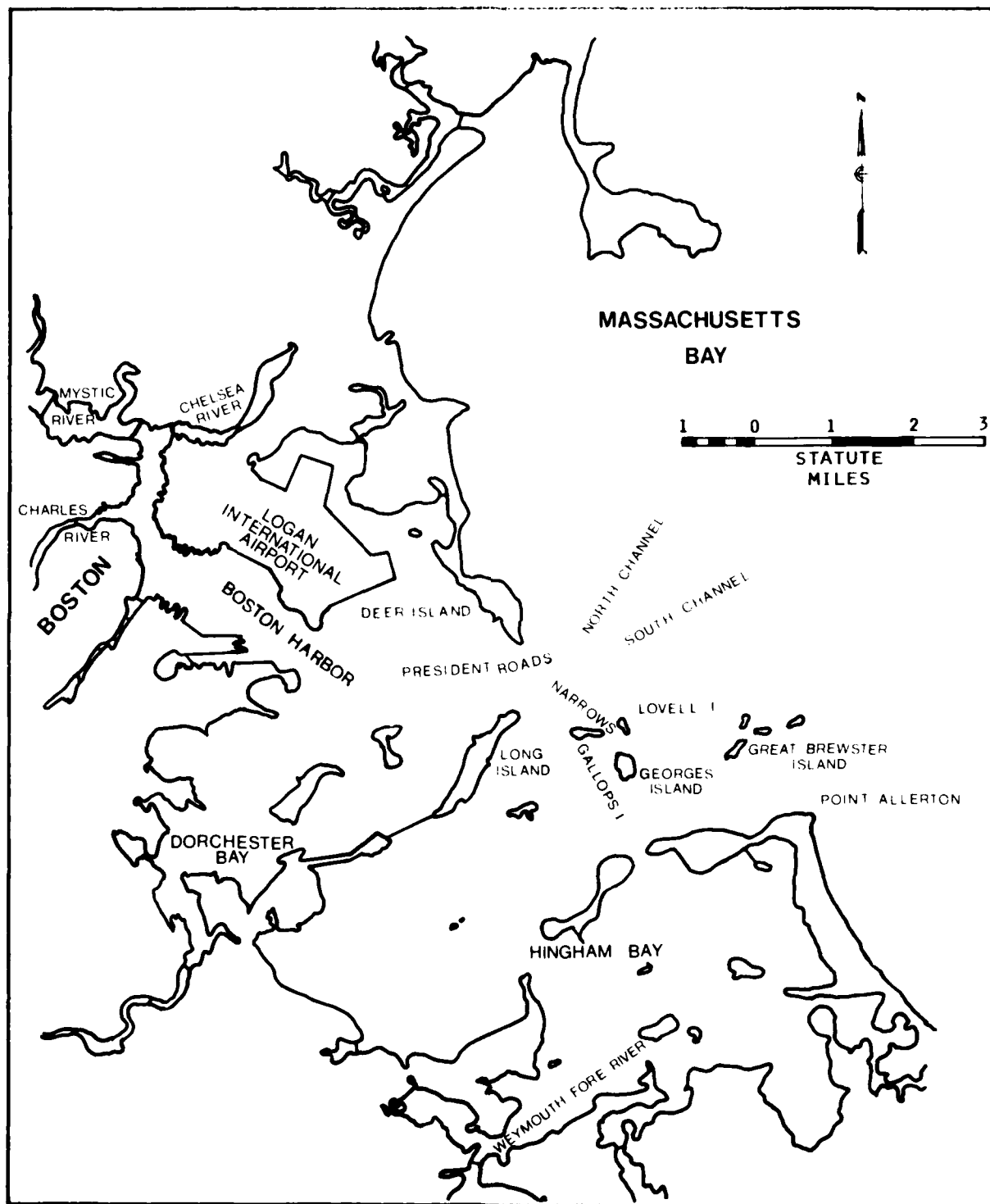


Figure XV-2. Boston Harbor and vicinity.



has depths up to 36 ft. The anchorage area along the northern side of the channel in the inner harbor is quite exposed to the wind and would have no protection from debris during a storm.

### 2.3 BERTHS (see Figure XV-3)

The Corps of Engineers Port Series No. 3 report for the Port of Boston describes 129 piers, wharves and docks. Many of these wharves are used for multiple purposes; the fuel and container wharves are the principal special purpose facilities.

Navy use of port facilities for docking is usually restricted to the following areas and piers:

(1) South Boston: Economic Development and Industrial Park (EDIC) north jetty, Army Base Terminal and Commonwealth pier.

(2) Boston: Coast Guard piers.

(3) Charlestown: Navy Shipyard piers 1 and 2 and the Boston National Historical Park.

#### 2.3.1 Economic Development and Industrial Park (EDIC).

The EDIC jetties are located on the south side of the inner harbor entrance, across the channel from Logan International Airport. This berth is used by carriers and other large ships. It is concrete-capped with steel-sheet pile bulkheads and is solid filled. The alongside depth is 40 ft and the deck height is 18 ft, both measurements relative to mean low water (MLW). It is bordered by an open apron inboard and the channel outboard.

#### 2.3.2 Army Base Terminal

The Army Base berths are in the Reserved Channel, whose entrance is located immediately outside the EDIC jetty in South Boston. They are constructed from concrete, faced with steel piling and solid filled. The alongside depths are 35 ft and deck heights are 17.8 ft relative to MLW. They are bordered by approximately 50-ft aprons and storage warehouses.

#### 2.3.3 Commonwealth South Boston Pier No. 5

This pier is in South Boston about 4000 ft above the EDIC jetty. Both the northern and southern sides are available for berthing. It is constructed of concrete with solid fill and steel pile face; concrete-decked extensions run along sides and face. This berth is frequently used by visiting Navy ships. The alongside depths are 40 ft, with 18 ft deck heights relative to MLW. A two-story steel-frame reinforced-concrete warehouse sits astride the pier. Apron width is 20 ft. Both sides have alongside lengths of 1200 ft and can handle large ships.

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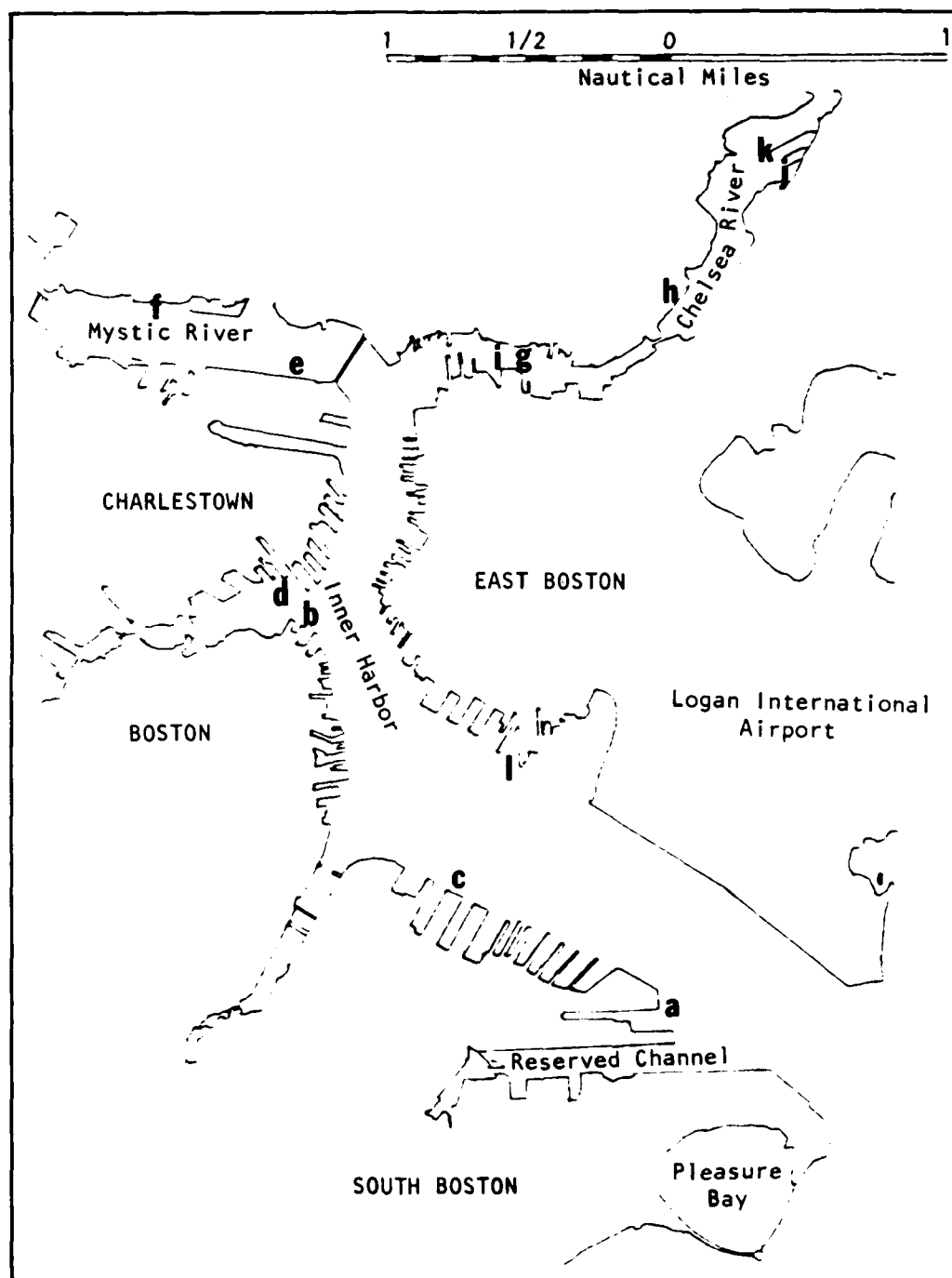


Figure XV-3. Boston Harbor and main berthing facilities.  
Boldface lowercase letters denote general locations of:

- |                                     |                     |
|-------------------------------------|---------------------|
| a - Army Base Terminal (EDIC Jetty) | g - Hess Oil Co.    |
| b - Coast Guard piers               | h - Amoco Oil Co.   |
| c - Commonwealth Pier               | i - Texaco Oil Co.  |
| d - Navy Shipyard                   | j - Gibbs Co.       |
| e - Moran Docks                     | k - Belcher, Inc.   |
| f - LNG Terminal                    | l - Bethlehem Steel |

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### 2.3.4 U.S. Coast Guard Support Center

The USCG Support Center is in Boston proper about a mile above the Commonwealth pier on the west bank of the inner harbor. There are five steel-piled, concrete-decked piers suitable for small to medium ships. Alongside depths range from 20 to 35 ft, with a 16-ft deck height relative to MLW. The piers are bordered by open aprons. Alongside lengths range from 260 to 550 ft.

### 2.3.5 Boston National Historical Park (Boston Navy Shipyard)

The Boston National Historical Park piers are located on the north side of the confluence of the Charles River with the inner harbor in Charlestown about 1600 ft above the Coast Guard Center. They are steel-piled, concrete-decked piers bordered by open aprons. Alongside lengths are less than 400 ft, which limits use of this area to frigate class or smaller ships.

### 2.3.6 Other Berthing

There are more than 100 other berths available throughout the Boston Harbor. The majority are located above the piers normally used by Navy ships. The main container wharf is the Morin Docks on the west bank of the Mystic River, just beyond the area of confluence of the Chelsea and Mystic Rivers. The LNG terminal is on the opposite bank (east side) of the Mystic River just upstream of the container wharf. Other well constructed berths in the Mystic River include Distrigas, Exxon, Prolerized Scrap, Amstar Sugar, Revere Sugar, and Atlantic Cement. Several well constructed tanker wharves are located along the north bank of the Chelsea River (Hess Oil, Amoco Oil, Gulf Oil, and Texaco).

There are also three finger piers used for receipt of petroleum products located near the turning basin in the upper Chelsea River (Gubb Co. and Belcher, Inc.) which are not considered suitable during high winds. Both the Massachusetts Port Authority piers and Bethlehem Steel Corporation pier 1 are located in East Boston near the outer portion of the inner harbor. These piers are adjacent to the airport, across the channel from the Commonwealth pier site. All of the above mentioned piers, except for the three finger piers in the upper Chelsea River, are well constructed.

## 3. HEAVY WEATHER FACILITIES AND HURRICANE ANCHORAGES

### 3.1 HURRICANE PLANS AND PREPARATION

SOPA will direct action to be taken by ships present during heavy weather preparations. The Commanding Officer, NAS, South Weymouth is assigned as Third Area Weather Coordinator by COMNAVBASEPHILINST 3140.1.

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### 3.2 TUG AVAILABILITY

There are two tug companies servicing the Boston Harbor. Boston Tow Boat Company and Boston Fuel Transportation, Inc. each have six tugs. These 12 tugs are adequate for normal operations, but could be hard-pressed during heavy weather conditions.

### 3.3 HURRICANE BERTHING (see Figure XV-3 for locations)

All of the berths normally used by the Navy are considered suitable for use during a hurricane except the EDIC jetty berth. This berth is very exposed with little or no protection from winds or wave action. The open spaces of the airport to the north, and outer harbor and bay to the east and south, provide very limited protection from the wind. The berth is totally exposed to the wave action in the channel which opens to the east.

In general all substantially constructed berths above the Coast Guard Center are considered suitable as hurricane berths because of the protection from winds provided by the surrounding terrain and the protection from high seas provided by the configuration of a river type harbor. However, finger piers and weakly constructed wooden piers are not considered suitable berths during any high wind situation.

In addition to the general construction of a berth, the height of the pier and allowable scope of lines should be considered in judging the suitability of a berth for use in high wind situations.

### 3.4 HURRICANE ANCHORAGES

There are no designated hurricane anchorages in the Boston Harbor. Among the general anchorages, only the area west of Georges Island (Anchorage 5) provides protection from the easterly winds. However, the approaches are narrow and there are numerous ledges and shoals in the area. In addition the bottom is generally covered with boulders which provide uncertain holding. The best area for use for anchorage during hurricanes is well to the southeast of Boston in Cape Cod Bay inside the hook of Cape Cod (Figure XV-1). This area is about 40 n mi from Boston Harbor and has been used by Coast Guard and local pilots to ride out storms. The usual problems related to vessels dragging anchor and to congested traffic must be anticipated.

#### 4. TROPICAL CYCLONES AFFECTING BOSTON

New England is not considered to be in the primary hurricane belt; however, some of the most destructive hurricanes of record have occurred there. Dunn and Miller (1964) noted eight intense New England storms which occurred in 1636, 1638, 1815, 1938, 1944, 1954 (two) and 1955 that are related to tropical cyclones. In general, tides and flooding are of greater concern than wind.

During the period of 1815 to 1938 no really extreme tropical cyclones affected the New England area. The 1938 tropical cyclone, however, is noteworthy for several reasons. It can be considered a typical Cape Verde storm. After moving across the entire subtropical north Atlantic, it recurved about 300 n mi east of southern Florida and accelerated northward in the southerly flow in advance of a strong midlatitude trough. The 1938 storm produced widespread damage throughout New England. Five minute average winds of 64 kt (and one minute average of 76 kt) were recorded at Boston during the passage.

The atmospheric and synoptic conditions favorable for a major hurricane to strike New England have been described by Dunn and Miller (1964). Such a tropical cyclone typically develops southeast of the Antilles, gradually recurves towards the vicinity of Cape Hatteras, and then accelerates very rapidly toward New England. The conditions that will support this type of event are:

- (1) A strong east/west atmospheric steering current over the tropical/subtropical North Atlantic.

- (2) Moist tropical air that has been advected poleward over the western Atlantic providing an extended region of atmosphere favorable for maintaining a tropical circulation.

- (3) The tropical cyclone does not make landfall until it reaches the northern U.S. east coast.

- (4) A well developed and intensifying large amplitude, long-wave trough is located over the east central United States.

Under the above synoptic conditions the tropical cyclone moves at speeds slightly above normal across the tropical Atlantic, feeding on the abundant moist tropical air; recurves northward prior to landfall while remaining in a moist warm environment; and then accelerates rapidly north to northwestward in the southerly flow in advance of the midlatitude large scale trough.

##### 4.1 CLIMATOLOGY

For the purposes of this study, any tropical cyclone that approached within 180 n mi of Boston is considered a threat. It is recognized that a few tropical cyclones that did not approach within 180 n mi may have affected Boston in some

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way, so to some extent this criterion is arbitrary. Track information on Atlantic tropical cyclones is available as far back as 1871. However, center wind information is not available for storms prior to 1886. The seasonal distribution of tropical cyclones given in Figure XV-4 is based on 94 years of data, 1886-1979. Data for the period 1871-1979 (109 years) were used for all other climatological figures.

Although tropical cyclones have occurred in the North Atlantic during all months of the year, all tropical cyclones that have threatened Boston occurred from June through November except for a single February threat in 1952 (Figure XV-4). Of the 83 tropical cyclones that threatened Boston in this 94-year period, 72 (87%) occurred in the months of August through October with the peak threat in September. The occurrence of tropical cyclones of hurricane intensity (winds  $\geq 64$  kt when within 150 n mi of Boston) has a marked peak during August and September with 23 out of 30 or 77% occurring during those months (1886-1979).

Figure XV-5 displays the storms as a function of the compass octant from which they approached Boston. It is evident that the major threat from tropical cyclones is from the south and southwest.

An average of 1.9 tropical cyclones per year have passed within 150 n mi of Boston during the period 1886-1979. Historically, slightly more than one out of three (30%) have been of hurricane strength. One way of interpreting this is to expect the passage of a hurricane-strength tropical cyclone every third year. However, the records do not support such a uniform frequency. During the period of 1944-1952, for instance, only one hurricane influenced Boston (September 1950), while in 1953 and 1954 four out of four passages of tropical cyclones were of hurricane strength.

The natural protection offered by the shape of the eastern coast of the United States, from south of New England to Cape Hatteras, essentially dictates that most recurving storms must either make a landfall first south of Hatteras or pass New England well offshore to the southeast. The majority of storms pass overwater well to the southeast of Boston, tending to follow the path of the oceanic Gulf Stream, and are of little threat to New England.

Occasionally, however, storms are accelerated on a more northerly track instead of the typical recurvature to the northeast. An example would be the disastrous 1938 hurricane which advanced rapidly up the east coast offshore, passed Hatteras, moved over central Long Island, and then moved over New Haven, Connecticut and thence north-northwest into Vermont. Thus, instead of passing New England offshore, the hurricane accelerated northward at an average rate of advance of 60 mph (52 kt), leaving Hatteras at about 1:30 AM LT on 21 September and reaching Connecticut at about 4:00 PM on the same day. Such a rate of advance would be difficult to handle for storm preparations even with today's more sophisticated warning methods.

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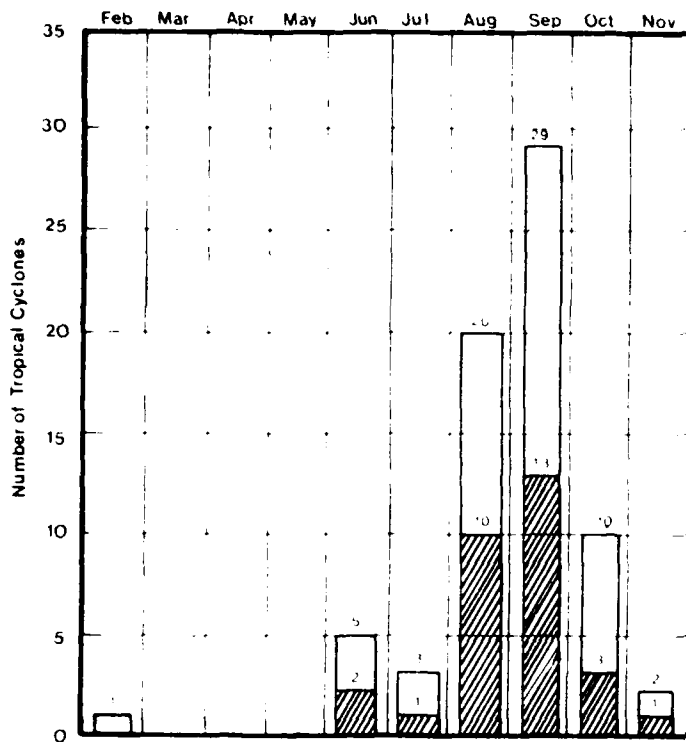


Figure XV-4. Seasonal distribution of tropical cyclones passing within 180 n mi of Boston, February-November (based on data from 1886-1979). Monthly totals shown above each column; numbers of threats of hurricane intensity shown by hatched areas.

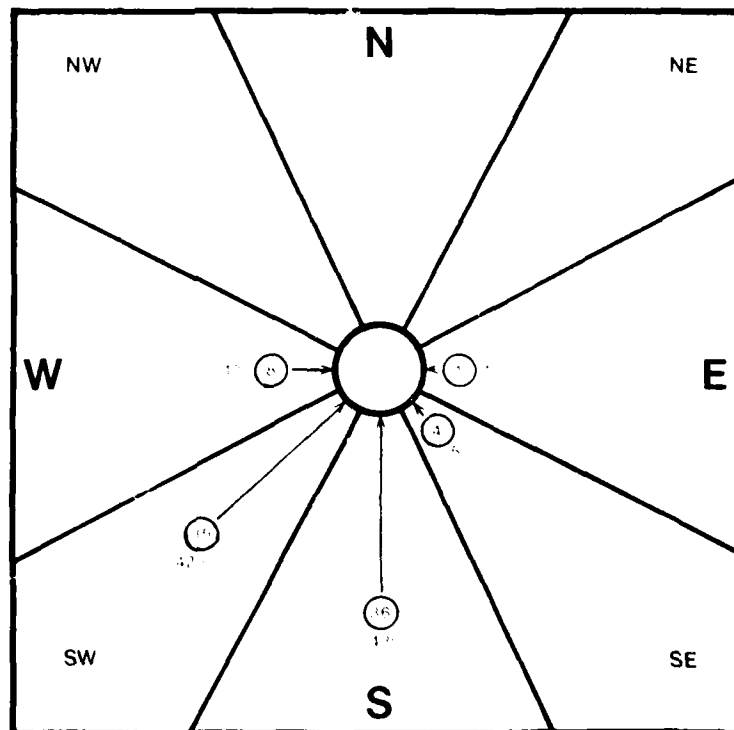


Figure XV-5. Directions of approach of tropical cyclones that passed within 180 n mi of Boston during the period 1871-1979. Numbers of storms approaching from each octant are circled; percentage figures are percent of total sample approaching from that octant.

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Figure XV-6 illustrates the very rapid approach of four such exceptional hurricanes which caused destruction in the New England region. With today's advances in meteorology, it is possible to identify those circumstances that led to the rapid acceleration of tropical cyclones toward the north, although rarely would a 60 mph speed of advance be forecast. Figure XV-6 shows that a hurricane can be offshore between Jacksonville and Cape Hatteras before its track begins to indicate it is heading for southern New England. The time at this point, where the departure from a normal recurvature track takes place, can be on the order of only 24-36 hours from passage at Boston.

Figures XV-7 through XV-10 are statistical summaries of threat probabilities based on tropical cyclone tracks for the years 1871-1979. The data base is presented seasonally with solid lines representing "percent threat" for the 180 n mi circle surrounding Boston. The heavy solid lines represent approximate approach times to Boston. In Figure XV-10, for example, a tropical cyclone located near 32°N, 75°W in September has about a 40 percent chance of passing within 180 n mi of Boston; and if the speed remains close to the climatological normal, it will reach Boston in about two days.

On an annual basis (Figure XV-7) the primary threat axis for Boston is along the East Coast through Hatteras with the axis splitting near South Carolina, with higher probabilities from the Bahamas and lesser probabilities from the Gulf of Mexico. Most threat storms pass to the southeast of Boston just off Cape Cod.

For late and early season storms, October through June (Figure XV-8), the major threat axis is overland passing through central Virginia from the Gulf of Mexico. The source region for most of these threat storms is the western Caribbean and the Gulf of Mexico. During the period 1888-1979, only four off-season (October-June) storms have approached within 180 n mi of Boston while still maintaining hurricane force ( $\geq 64$  kt) winds.

In June 1893, a hurricane moved from the extreme western Gulf of Mexico northeastward across northern Florida and over the coastline to just north of Hatteras, and continued northeastward passing 141 n mi southeast of Boston with 80 kt center winds. Boston experienced light rain and light northeasterly winds. The other three hurricanes, two in October and one in November, formed well northeast of the Bahamas and remained offshore until beyond Boston. The November 1888 hurricane passed the closest of these off-season storms (93 n mi to the east), producing a maximum one hour average wind of 53 kt and a total precipitation amount of 4.36 inches.

During July and August (Figure XV-9) the axis is still to the southwest overland, but splits near South Carolina with the primary threat thence from the Bahamas and eastward to the Cape Verde region. The source for almost all July/August threatening tropical cyclones is the subtropical North Atlantic. Most threat storms from July through September recurve over water, passing Boston to the southeast.



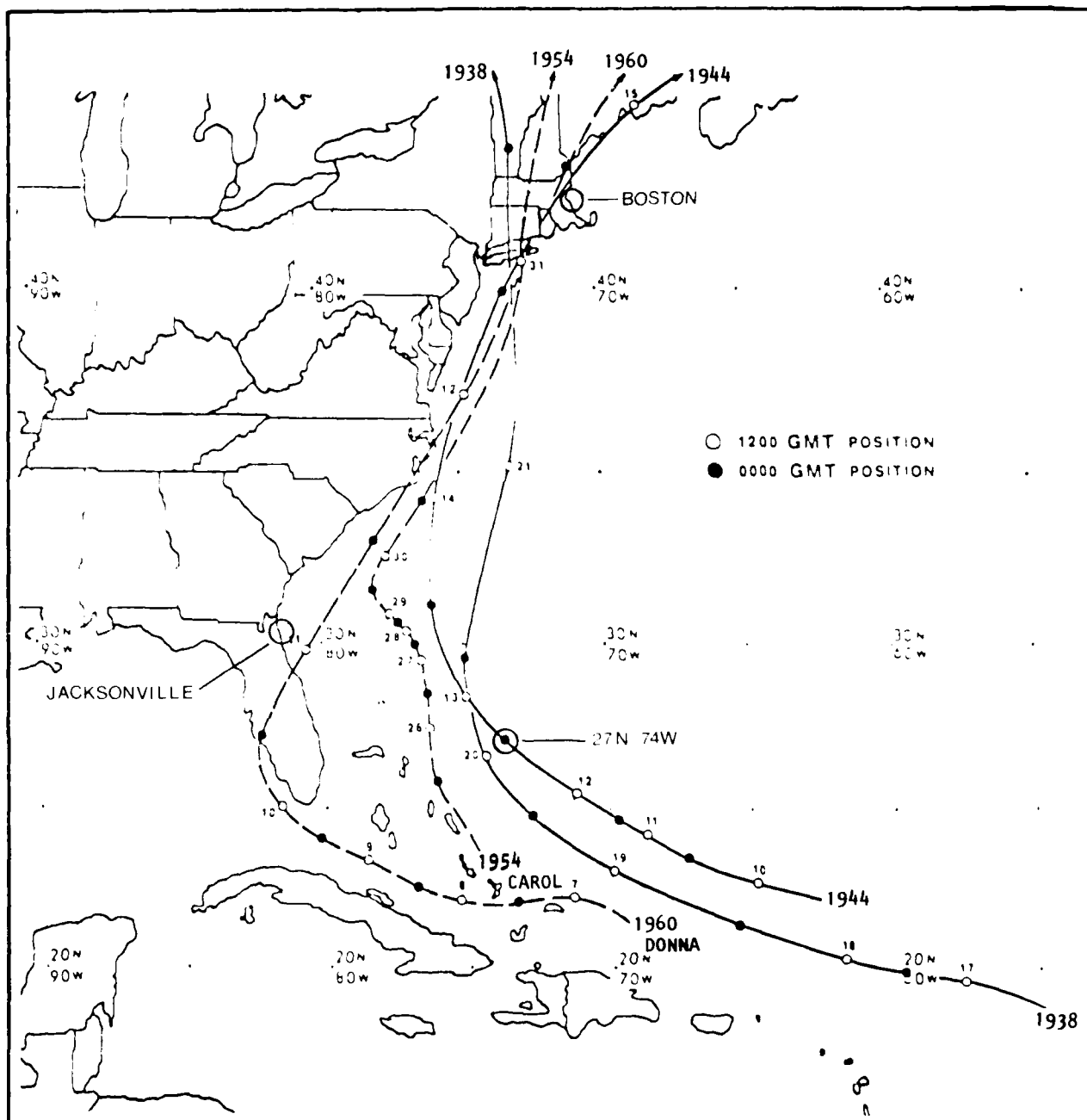


Figure XV-6. Examples of fast-moving hurricanes that impacted New England.

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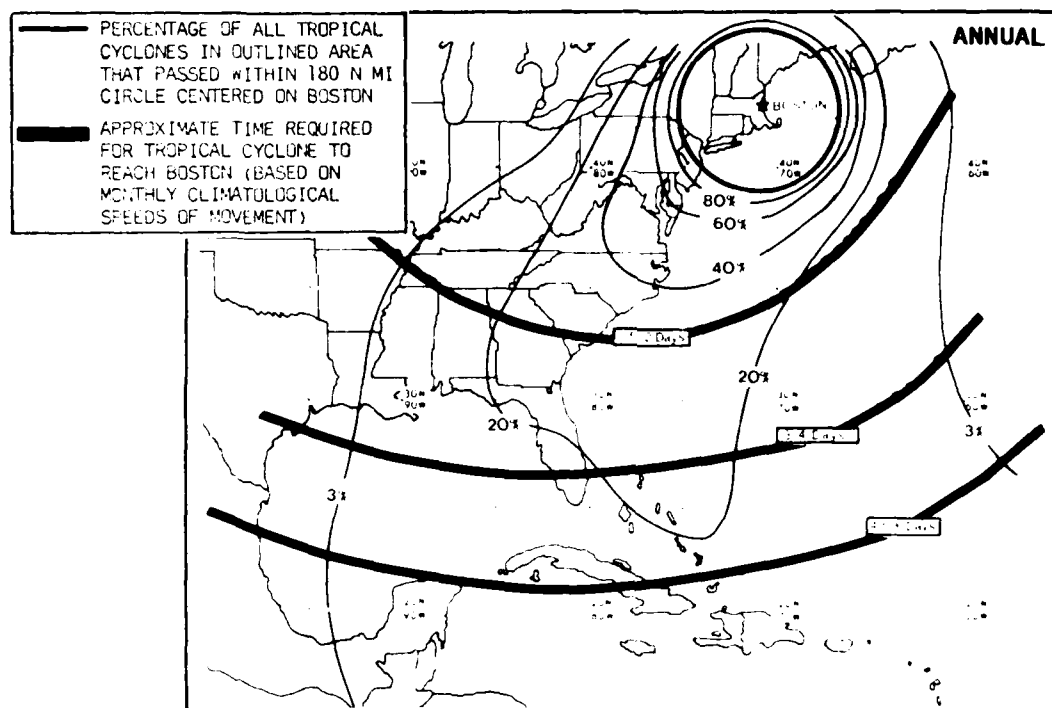


Figure XV-7. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi of Boston, based on data from 1871-1979.

The threat axis of probability shifts to just offshore by September (Figure XV-10) with the source region continuing to be the subtropical North Atlantic.

The times to CPA presented in Figures XV-7 through XV-10 should be used with caution, because it is the exceptionally fast moving storm that poses the greatest danger to Boston, not the "average" storm. For example, Figure XV-10 indicates that a September storm located near 27°N/74°W should reach Boston in about 3 or 4 days, based on climatology. However, the 21 September 1938 hurricane is believed to have traveled this distance in about 30 hours (refer to Figure XV-6). The tendency for acceleration of tropical cyclone movement after moving north of 30-35°N is evident in all the charts showing times to CPA. Comparing the distance from Boston to the 1 1/2-2 day contour to the distance between the longer time periods indicates significantly faster movement during the latter 1 1/2-2 days.

Typical speeds of movement for hurricanes within 180 n mi at CPA varies from 25-30 kt for those crossing near the New England coast to 20-25 kt for those passing offshore to the southeast.

The months of late August, September and early October historically are the greatest threat months for a direct overwater approach to Boston. This period would coincide with the optimum time for the simultaneous occurrence of the following factors:

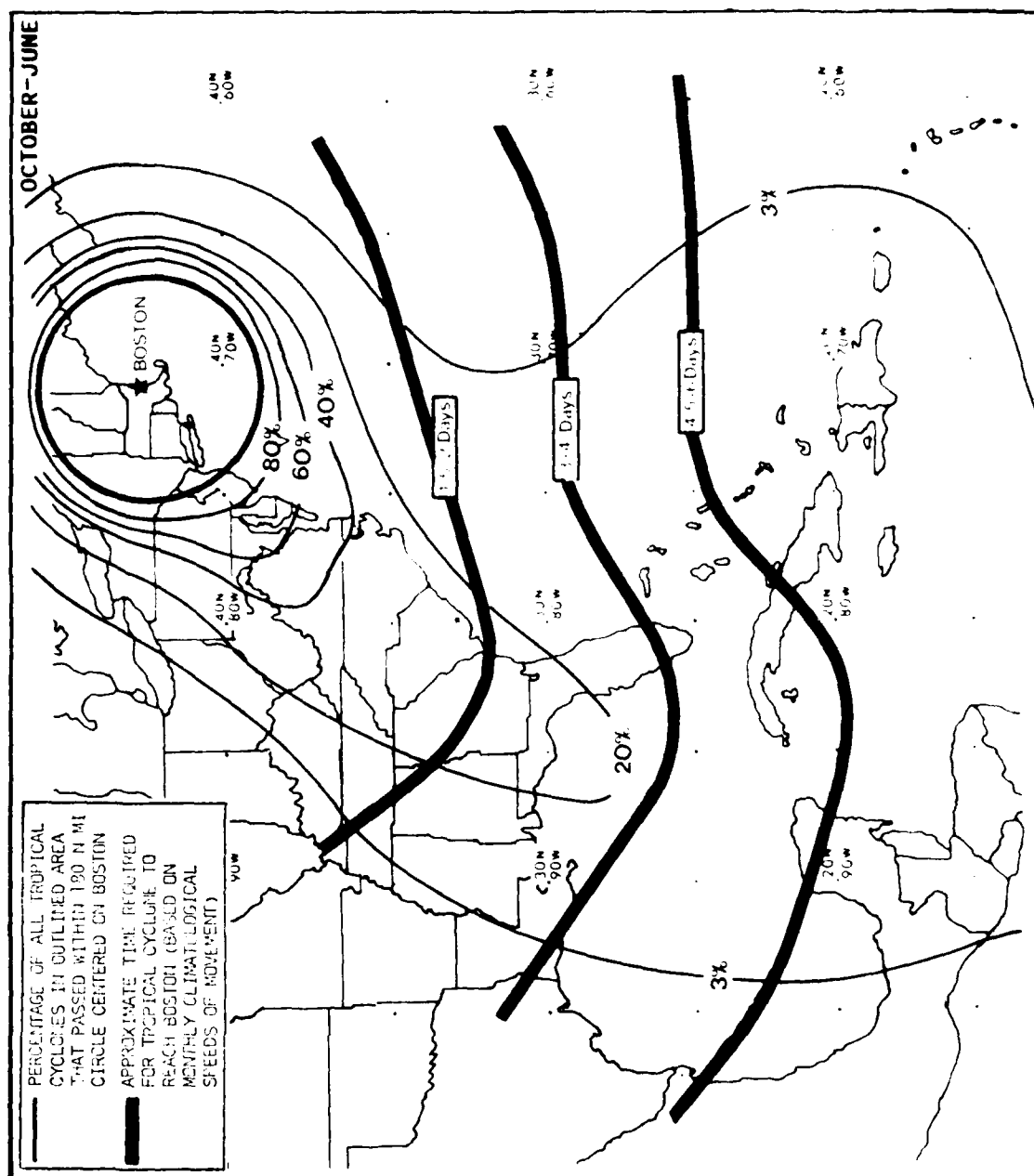


Figure VX-8. Probability that a tropical cyclone will pass within 180 n mi of Boston (circle), and approximate time to closest point of approach, during October through June (based on data from 1871-1979).

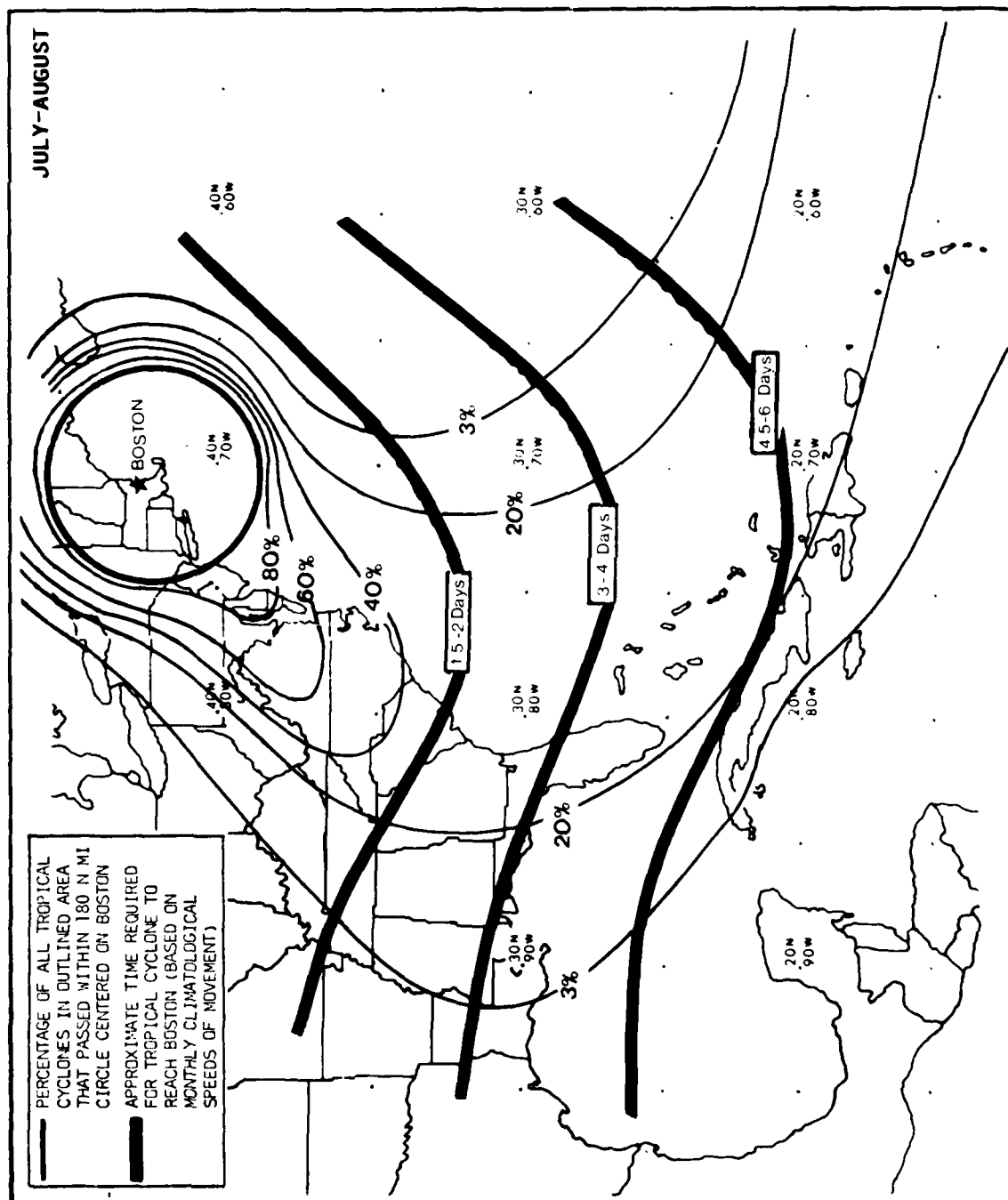


Figure XV-9. Probability that a tropical cyclone will pass within 180 n mi of Boston (circle), and approximate time to closest point of approach, during July and August (based on data from 1871-1979).

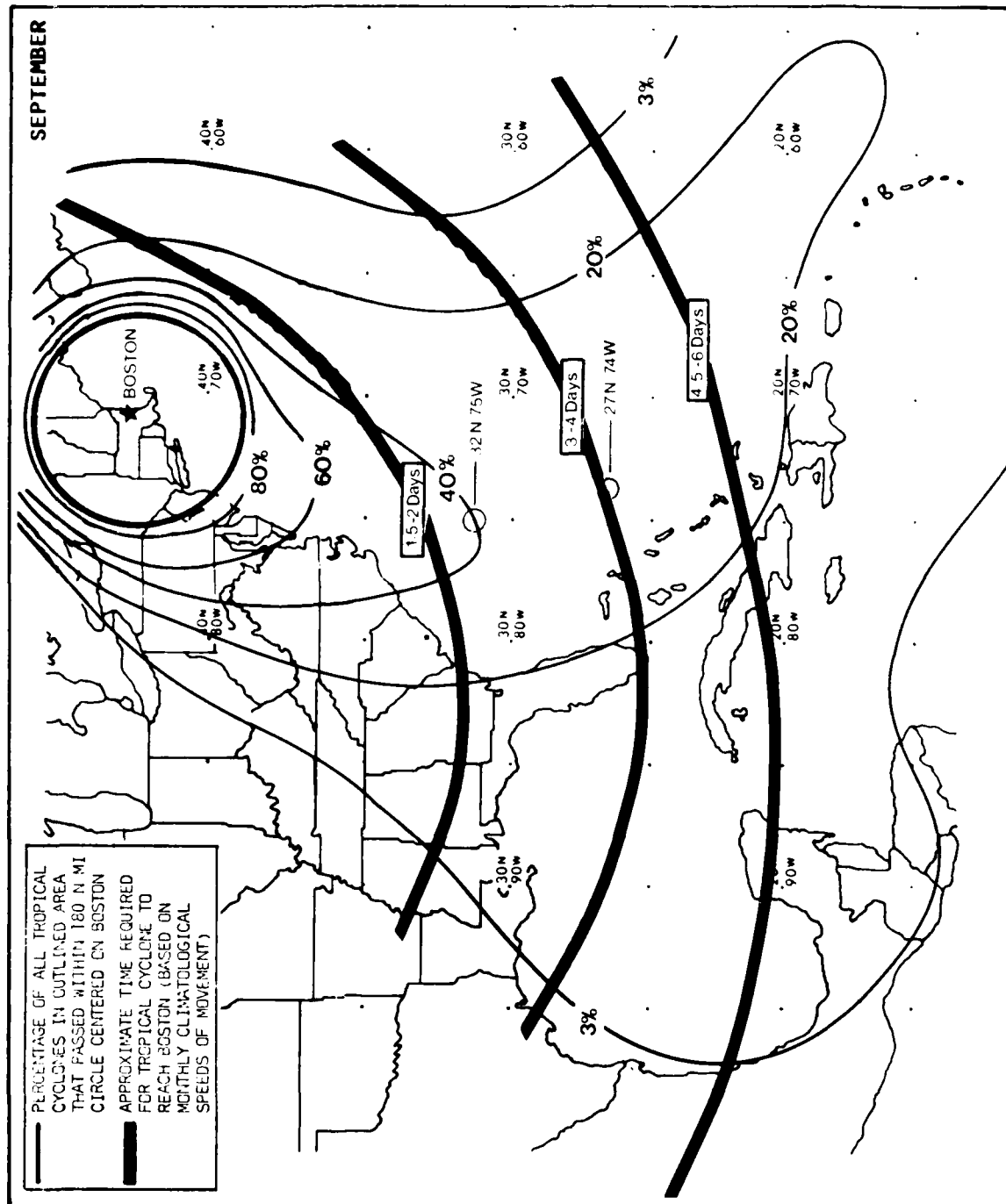


Figure XV-10. Probability that a tropical cyclone will pass within 180 n mi of Boston (circle), and approximate time to closest point of approach, during September (based on data from 1871-1979)

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- (1) Greatest tropical cyclone activity.
- (2) Strong North Atlantic subtropical high pressure system.
- (3) Deep atmospheric upper level trough lying over the East Coast.
- (4) The primary tropical cyclone generation area is the subtropical North Atlantic.

Factors 1, 2 and 3, combine to modify the normal recurvature of a tropical cyclone and instead accelerate and steer it rapidly north from Cape Hatteras into southern New England. Factor 4 causes the tropical cyclone to be properly positioned for an overwater approach.

Unfortunately for New England, such storms lose little energy as they rapidly traverse the colder water between the north wall of the Gulf Stream and Long Island, as would be expected of tropical cyclones. This may be explained by their adoption of extratropical characteristics at higher latitudes or by their reduced interaction with the surface at such high speeds of advance. Either way, the circumstances described above combine to present a serious threat of destruction to New England.

### 4.2 LOCAL WEATHER CONDITIONS DURING HURRICANE PASSAGE

The primary sources of the weather data examined in this discussion were the hourly observations from the Weather Bureau Station. Historical data for the period 1885-1958 were obtained for Blue Hill Observatory site. Supplemental data in various summary and observational form, for several sites in and around Boston, were also reviewed. Records from all sites were reviewed for those periods when a tropical cyclone was within 360 n mi of Boston. The sites and periods of records for hourly observations were as follows:

Boston WBAS	1936-1979
Boston WBO	1893-1934
Boston L/S	1958-1973
Squantum	1943-1953
Salem Coast Guard	1949-1966
Race Point L/S	1958-1979
Eastern Point	1964-1979
Hanscom	1943-1973
Blue Hill Observatory	1885-1958

During the 44-year period 1936-1979, 13 hurricane-force tropical cyclones passed within 180 n mi of Boston. Table XV-1 lists various aspects of these 13 storms (plus tropical storm Diane of August 1955, which caused record rainfall in the New England region).

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Table XV-1. Center data and related weather associated with hurricane passages within 180 n mi of Boston (1936-79).

HURRICANE DATA				RELATED WEATHER IN BOSTON AREA				
Date (Name)	SOA (kt)	DIR/CPA (n mi)	CNTR (kt)	Max Wind (kt) & Sustained Gusts	Surge Ht (ft)	Precip (ins) 24 hr/max 6 hr		Comment
9/19/36	25	E 102	91	N 34 & 37	2.0			
9/22/38	40	W 109	91	S 63 & 76	2.5			
9/2/40	21	E 110	74	NE 29 & 30				
9/15/44	28	W 17	104	NE 52 & 63	3.9	2.59	2.37	Max gust of 85 kt
9/12/50 Dora	17	E 165	91					No significant weather
8/15/53 Barbara	20	E 124	79	W 21 & 34		.93	.75	Gust over bay 43 kt
9/7/53 Carol	16	E 156	91	WNW 18 & 25				
8/31/54 Carol	31	W 61	91	SE 75 & 87	3.6	2.58	1.98	
9/11/54 Edna	40	E 60	109	NW 64 & 76	3.2	5.63	3.33	
8/19/55 Diane	13		40	ENE 42 & 48	Negative	7.06	4.88	Heaviest 36 hr rain in history 11.94"
8/29/58 Daisy	22	E 147	117					No significant weather
9/13/60 Donna	32	W 39	96	S 54 & 69	2.6	2.95	2.02	East of Track Boston side: strongest winds, gusts 65-87 kt max gust 122 kt Blue Hill Observatory. Hundreds of small craft destroyed. 2-4" rain. West of Track Max gusts 65 kt Heavy rain 4-6"
8/29/62 Alma	14	E 104	74	N 29 & 44		1.69	.94	
9/9/69 Gerda	14	E 102	110	NW 25 & 32		2.19	1.58	

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The 1954 storms, Carol and Edna, offer an interesting comparison of storms passing to the east or west of Boston. Carol in late August had a closest point of approach (CPA) of 61 n mi to the west with a speed of advance (SOA) of 32 kt and center winds of 91 kt. Less than two weeks later, Edna passed 60 n mi to the east with a SOA of 40 kt and 109 kt center winds. Minimum sea-level pressures were 976 mb for Carol and 973 mb for Edna. While Edna had stronger center winds, was moving faster, and produced a slightly lower pressure reading and while the CPA's were nearly equal, Carol produced maximum one minute averaged winds and peak gust readings of 74 and 87 kt from the southeast and Edna only 64 and 76 kt from the northwest (WBAS East Boston).

These differences can be related to the additive factor of the SOA of the right semicircle winds relative to the direction of movement. On the other hand, the rainfall for Edna (the storm passing to the east) was more than double that during Carol (passing to the west). The records indicate that heavy rainfall and flooding occur to the west of the storm track and maximum winds and damage to the east of the storm track. Tidal surge heights appear independent of direction of passage and more a function of storm strength and proximity.

Mariners should be aware that all wind records used in this study are from land stations and that a ratio of 1.6:1 has been found to be a representative ratio for estimating maximum winds over open water areas from adjacent land reports (Hsu, 1981). Thus wind speeds of 100 kt were likely over the outer harbor area during several of the hurricane passages.

Figure XV-11 shows the approximate tracks of the six most damaging hurricanes that passed within 180 n mi of Boston during the period 1936-1979. All of these storms produced widespread damage in the Boston area. Improved warning systems helped alleviate property damage and loss of life in the storms of 1954, '55 and '60. In storms of this type it is likely that any pleasure craft or small boats that are not removed from the water or moved to known havens will be heavily damaged or destroyed. The threat comprises the three elements of high wind, heavy rainfall, and rising sea level. All must be given consideration in preparing for a hurricane passage.

People of the Boston area are much more attuned to the winter Northeaster type storms\* than the hurricane threat. Some unique characteristics of the hurricane that differ from those of the Northeaster must be kept in mind: (1) the prime threat hurricane is most likely to occur during the fair weather sailing season in September; (2) the speed of approach of these prime threat hurricanes is quite rapid, 25-35 kt; (3) the wind direction is likely to rotate through the entire compass with the passage of a hurricane; and (4) it is the nature of man not to be concerned about events that happen infrequently.

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\*Northeaster - An extratropical storm, most common between September and April, which typically forms within 100 n mi of the east coast between 30-40°N and progresses northeastward. Maximum intensity is reached off New England, bringing precipitation and northeasterly gale force winds to the coastal regions for a day or more.



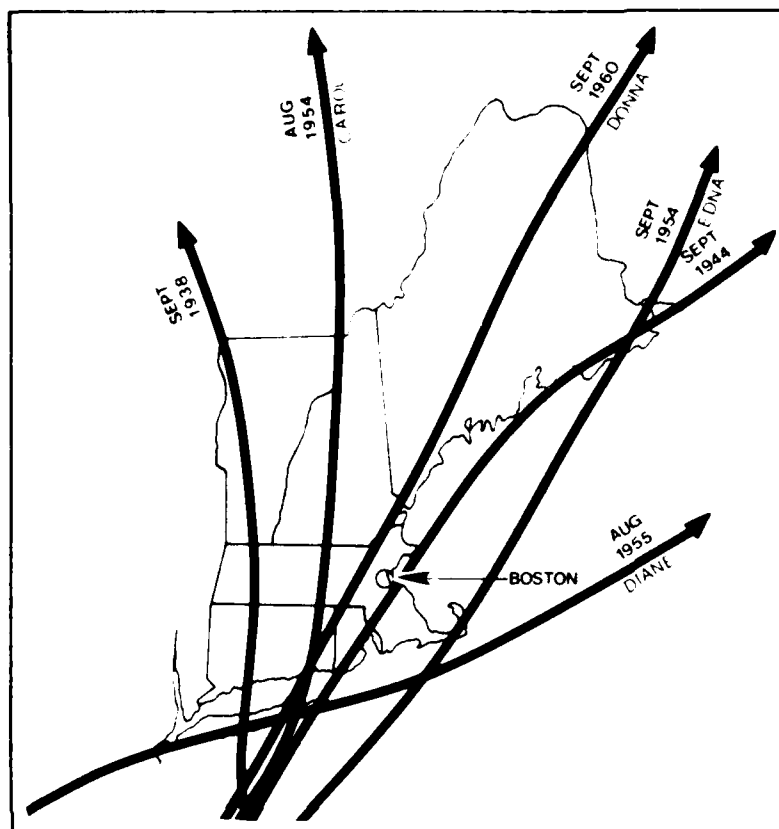


Figure XV-11. Tracks of major hurricanes that affected Boston during the period 1936-1979

#### 4.3 WAVE ACTION

The inner Boston Harbor is somewhat protected by Deer Island to the north and east and Long Island to the southeast. Numerous other smaller islands also provide some shelter from the open bay/ocean wave energy. However, easterly winds and seas will cause wave related problems. Most of the lower inner harbor is exposed to the east and vessels in this area, unless berthed at well protected piers, will experience high wind waves. While the piers and wharves of Boston have generally been constructed to handle the normal 9-10 ft tidal range, some local flooding is experienced during extreme tide conditions. In the event of a storm passage at high astronomical tide, waterfront areas would be exposed to wave action. Water levels of 1 1/2 ft over the piers have been recorded at the Naval Shipyard.

#### 4.4 STORM SURGE AND TIDES

Storm surge during hurricanes generally has not been a major problem for the Boston Harbor area. The highest surge value on record is the 3.9 ft that occurred with the September 1944 hurricane (Harris, 1963). The 1954 hurricanes, Carol and Edna, produced 3.6 and 3.2 ft surge heights. With a normal tidal range of 9 to 10 ft, surge heights of 2-4 ft will generally not be of great concern. Of course, a 4 ft surge at extreme high tide (range of about 14 ft at

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Boston) would cause considerable flooding; when this was topped by wind waves from the east, further problems would develop. A compounding adverse effect of surge and easterly wind waves is the restriction of the outflow from the various rivers that flow into and form the inner harbor. Such a restriction further increases the flood problem along the lower portions of the rivers, which usually experience increased flow during a hurricane passage as a result of heavy precipitation.

### 5. THE DECISION TO EVADE OR REMAIN IN PORT

The inner harbor portion of the Port of Boston is considered a hurricane haven; therefore, remaining in the inner harbor or moving to that portion of the harbor is the recommended action.

Instructions for disaster preparedness by Navy ships are found in SOPA(ADMIN),INST 5450.1. SOPA will direct action to be taken by Navy ships present. Commanding Officer, NAS South Weymouth, is assigned as Third Area Weather Coordinator and will communicate weather warnings and Conditions of Readiness to SOPA and SOPA(ADMIN). A U.S. Navy Communications Center is not available in Boston, so ships remaining in excess of 72 hours should make guard shift arrangements with Communications Center, Commander, First Coast Guard District.

With the approach of a hurricane, the decision to execute precautionary measures must be made in a timely manner. Precautionary action should be based on consideration of four general factors: vessel characteristics, harbor conditions and available berthing, most recent hurricane warning forecast, and storm climatology history.

Individual vessel factors are best determined by those responsible for each vessel. Vessel characteristics, in addition to seaworthiness, include such factors as anchorage or moored location and tug and/or pilot needs.

#### 5.1 PRECAUTIONARY ACTION RATIONALE

Ships berthed in the upper portions of Boston harbor should remain in port. In the lower inner harbor, ships berthed in exposed positions or structurally weak berths, should be reberthed or should leave the harbor.

If operational or logistical circumstances demand sortie action, the recommended procedure is to steam due east to clear the shoal waters and then continue evasion as dictated by the storm. (See Section 6 for evasion at sea rationale.) Due to the high speed of advance of hurricanes that threaten the Boston area, evasion to the open Atlantic involves a considerable risk of being overtaken by the hurricane.

## 5.2 THREAT ASSESSMENT

Timing of any precautionary measure is always extremely critical. The fast, northward-moving hurricanes that constitute the prime threat can cause the Boston area to go from readiness condition IV to condition I in a matter of a few hours. Note that Figures XV-7 through XV-10 show that the climatological position for the average storm 48 hours from Boston is near the latitude of southern South Carolina, while the 72-hour position is near central Florida.

However, Figure XV-6 -- examples of fast-moving hurricanes that caused significant damage in the New England region -- shows the following approximate times to closest point of approach of Boston from the latitude of southern South Carolina:

- |     |                   |            |
|-----|-------------------|------------|
| (1) | 21 September 1930 | - 11 hours |
| (2) | 15 September 1944 | - 24 hours |
| (3) | Carol 1954        | - 27 hours |
| (4) | Bonna 1960        | - 24 hours |

## 5.3 THREAT SOURCES

The sources of tropical cyclones and their approaches to Boston harbor are varied. The following five subparagraphs address the various sources of storm sources and approaches.

### 5.3.1 Rationale for the Primary Threat

Storms approaching Boston from between the east coast and the 100°W meridian constitute the primary threat. The late August through September period is the time this type of storm is most likely to occur. If the forecast is for the storm to accelerate on a northerly track, then due consideration relative to precautionary measures should be given. Ships at exposed or poorly constructed berths should be rebertned.

### 5.3.2 Rationale for Storms Approaching from Over Land

Storms approaching from over land (landfall south of Long Island) are of limited threat due to their reduced intensity. These storms are not likely to generate wind or surge problems at Boston, but storms of this type which recurve and pass south of Boston can cause heavy rainfall (Diane 1955 track, Figure XV-11) and related flooding problems (Table XV-1).

### 5.3.3 Tropical North Atlantic Hurricane Near the Bahamas

Tropical cyclones approaching from this sector in close proximity to the east coast are Boston's greatest threat for the dangerous completely-overwater approach. They are also the most likely candidates for rapid acceleration northward. If the storm becomes one of the unusual, northward-accelerating hurricanes that are particularly dangerous to Boston, minimal time is available for precautionary action since the time schedule will be compressed. Hurricanes

## BOSTON, MA

from near the Bahamas which actually strike the Atlantic coastline of the southern United States would not generally be considered a threat, since historically they have weakened considerably. An exception would be those hurricanes that pass over a small area of land, particularly Cape Hatteras, such as Hurricane Donna in 1960.

### 5.3.4 Tropical North Atlantic Hurricanes Farther Northeast of Bahamas

Based on records of this century, tropical cyclones north of approximately 27°N latitude and east of about 70°W longitude have a low probability of being a destructive threat to Boston. However, for a major hurricane in this area predicted to threaten Boston, precautionary actions are advisable.

### 5.3.5 Gulf of Mexico and West Caribbean Hurricanes

Tropical cyclones approaching from this area are not considered a threat to shipping in the Boston area. While the passage of such storms within 100 nmi of Boston occurs fairly often, their long track over land greatly reduces the wind threat and nearly assures their change to an extratropical system. They may cause local flooding due to heavy precipitation.

## 5.4 USE OF ANCHORAGES

The harbor deep-draft anchorage areas are north of President Roads, in Nantasket Roads, between Georges Island and Long Island, and north of the channel entrance to the inner harbor (see chart 13270). The anchorage on the west side of Georges Island is sheltered from easterly winds but has questionable holding. This area is used by vessels during periods of strong easterly winds. The anchorage north of President Roads has a blue mud bottom and fairly good holding but is space-restricted and has numerous surrounding shelves and shoals. The anchorage north of the inner harbor entrance channel has a soft mud bottom and poor holding qualities and is not an appropriate anchorage during strong wind conditions. The best hurricane anchorage (see Para. 3.4) is 40 nmi southeast of Boston Harbor in Cape Code Bay, within the hook of Cape Cod.

## 5.5 RETURNING TO HARBOR

After the passage of a hurricane, entering the harbor may present hazards. There may be wrecks in the channels, large floating debris, and damage to the piers. Alongside services may well be disrupted by the flooding associated with storm surge. There is a very high probability that channel markers and other navigation aids will have shifted position or become otherwise unreliable.

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### 5.6 RUNNING FOR SHELTER

Ships at sea that are seeking shelter should consider several factors relative to Boston. Boston Harbor is considered to be a refuge from hurricane weather. Suitable berthing is available. The anchorages in the harbor area are not considered suitable during hurricane conditions because of their limited size, surrounding shoals, ledges and rocks, and varying holding characteristics. Harbor facilities (tugs and piers) are generally available and harbor traffic is not congested. The numerous shoals and rocks in the outer harbor region make navigation during heavy weather particularly dangerous, thereby necessitating arrival prior to onset of storm conditions.

### 5.7 ADVICE FOR SMALL CRAFT

Small craft should be either removed from the water to positions above projected flood levels or bottom moored in protected areas. There are no recommended small craft hurricane mooring facilities in the main harbor. During hurricane Donna in 1960, hundreds of small boats and pleasure craft were ripped from their moorings and smashed against rocks or seawalls. Similar damage was inflicted by earlier severe storms in the areas. Small craft berthed along the western bank of the inner harbor below the confluence of the *Mystic and Chelsea Rivers* appear particularly vulnerable to damage by hurricane passage.

## 6. RATIONALE FOR EVASION AT SEA

If sortie and evasion at sea is necessary, then reaching the deep water beyond the continental shelf is advisable. Large areas of shoals exist within Massachusetts Bay (Stillwagen Bank) and over the Continental shelf area of the open ocean (Georges Bank). These areas produce the dual hazards of limited draft and shallow water wave action in a totally exposed open ocean area and should therefore be avoided during evasive action.

When threatened by weaker tropical systems, such as a tropical storm, or if rapid development or speed of approach makes sortie hazardous, then some local berthing or anchorages are preferred (Para. 3.4). When evasion at sea is contemplated, the importance of an early decision to sortie cannot be over-emphasized. Each threat must be judged on its own merits. The most likely threat scenarios and recommended actions are described in the following three subparagraphs.

### 6.1 TROPICAL NORTH ATLANTIC HURRICANE NEAR THE BAHAMAS

Tropical cyclones approaching from this sector in close proximity to the east coast are Boston's greatest threat for the dangerous completely-overwater approach. They are also the most likely candidates for rapid acceleration

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northward. The only sortie options from a threatening hurricane located near the Bahamas is either to evade within the confines of Massachusetts Bay or head southeast with intent to clear to the east side. This action requires crossing the track (crossing the T) and requires extra caution. Heading directly east may not give enough clearance if the storm moves rapidly northeast. Since the majority of such storms do accelerate along a track in a northeasterly direction well south of Cape Cod, any sortie must be initiated early, otherwise the vessel can easily be over-run before it is clear.

For a fast-moving (30+ kt) storm, the seas and most wind will not project any appreciable distance ahead of the storm, whereas in the case of the slower-moving storm, swell and wind extend for considerable distances (hundreds of miles) from the storm's center. If the storm becomes one of the unusual, northward-accelerating hurricanes that are particularly dangerous to Boston, less time is available to sortie since the schedule will be compressed; however, it will be easier to clear to the east of the storm.

In any event, if a vessel intends to sortie to the open ocean, an early decision must be made, preferably with the storm no closer climatologically than 48 hours. Hurricanes from near the Bahamas which actually strike the Atlantic coastline of the southern United States would not generally require a sortie since historically they have weakened considerably. An exception would be those hurricanes which pass over a small area of land, particularly Cape Hatteras, such as Hurricane Donna in 1960.

### 6.2 TROPICAL NORTH ATLANTIC HURRICANES FARTHER NORTHEAST OF BAHAMAS

Based on records of this century, tropical cyclones north of approximately 27°N latitude and east of about 70°W longitude have a low probability of being a destructive threat to Boston. These storms do not generally warrant a sortie. However, for a major hurricane in this area predicted to threaten Boston, evasion may be advisable. In this case the most probable direction for the storm to travel, if the warning is not correct, is north-northeast. Therefore the best evasion route would be to the southwest along the U.S. east coast. This would place the vessel in the safe semicircle if the forecast route is correct, and allow the vessel to evade the storm that recurves to the northeast.

### 6.3 GULF OF MEXICO AND WEST CARIBBEAN HURRICANES

Tropical cyclones approaching from this area are not considered a threat to shipping in the Boston area and would not warrant evasion. While the passage of such storms within 180 nmi of Boston occurs fairly often, their long track over land greatly reduces the wind threat and nearly assures their change to an extratropical system. They may cause local flooding due to heavy precipitation.

# REFERENCES

1. J. W. Smith and J. L. Miller, 1964: Atlantic Hurricanes, Louisiana State University Press, 277 pp.
2. Smith, J. W. 1966: Characteristics of the Hurricane Storm Surge; U.S. Dept. of Commerce, Technical Paper No. 44, Washington, DC.
3. Smith, J. W. 1967: Model for estimating offshore winds from onshore meteorological measurements. Boundary Layer Meteorology, 20, pp. 341-361.
4. Neumann, G. L., G. R. R. and S. Darwin, 1970: Tropical cyclones of the North Atlantic Ocean, 1911-1969; National Climatic Center, Asheville, NC, in cooperation with the National Hurricane Center, Coral Gables, FL.
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6. J. W. Smith, Jr., and J. L. Jarnell, 1970: Tropical cyclone evasion planning, Naval Weather Research Facility Technical Paper No. 16-69.
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## XVI. NEW YORK, NEW YORK

### SUMMARY

New York Harbor is recommended as a hurricane haven on the basis of the considerations discussed below.

Tropical cyclones which have caused sustained winds of hurricane force ( $\geq 64$  kt) in the New York Harbor area are rare events. Normal hurricane recurvature at this latitude and the geographic features of the New York Harbor area combine to provide protection from the more dangerous tropical cyclones.

New York is a large, natural harbor with many excellent berthing facilities and good deep-water anchorages. Natural topographic features and numerous man-made structures offer good wind protection. The bathymetry and orientation of the harbor relative to the normal path of hurricane passage tend to mitigate wind/wave and ocean swell danger. Storm surge, however, is a significant threat to the harbor.

Three additional factors also apply here:

(1) The probability is low that a tropical cyclone of hurricane strength will strike New York Harbor.

(2) The decision to leave New York Harbor to evade at sea must be made very early to allow safe clearance, because of the normal increased speed of advance and likely recurvature of the storm.

(3) Excellent berthing is available.

Normal hurricane berthing is recommended unless the harbor winds are forecast to be near or above hurricane strength. Reberthing in the most protected berth available and extraordinary preparation is then recommended, with particular attention to possible storm surge threat.

This hurricane haven evaluation was prepared by A. J. Compton and J.D. Jarrell of Science Applications, Inc. (SAI), Monterey, CA 93940

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### 1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

New York Harbor, which is located along the western shore of Long Island,\* extends from the confluence of the Hudson and East Rivers in the north to Lower New York Bay in the south, as shown in Figure XVI-1. It includes Jamaica Bay to the east and Sandy Hook Bay to the south. New Jersey ports of Perth Amboy, Port Elizabeth, Port Newark, Bayonne and others are accessible through tributaries which empty into New York Harbor.

The harbor complex is located between the New England lowlands and the Atlantic coastal plain. Elevations range from sea level to a high of over 400 ft in the Richmond area on Staten Island. Lower New York Bay is open to the Atlantic Ocean in the quadrant from the east around to the south, while Long Island Sound opens to the northeast. The Upper Bay opens to the south via the Narrows to the Lower Bay.

The western end of Long Island Sound is subject to channeling of wind and water from the east as is New York Harbor from the southeast. Short-period wind-wave setup, as well as storm surge, is possible in the event of a nearby hurricane landfall (e.g., Donna in 1960). The physical geography of New York Harbor and Long Island Sound allows sufficient fetch for wind-wave damage to occur, and both are susceptible to the buildup of water in semi-closed bays causing abnormally high levels.

Deep ocean swell is effectively blocked from entrance into Long Island Sound by Block Island and associated shallows, as well as by the restrictive angle at the eastern end of Long Island. Ocean swell is shoaled upon shallows at the entrance to Lower New York Harbor, giving some protection to the harbor proper. Figure XVI-2 depicts the physical geography of the area.

### 2. THE HARBOR AREA AND ITS FACILITIES (Figure XVI-1)

The New York/New Jersey Port area is one of the largest commercial marine complexes in the world. New York Harbor is a large, protected, natural harbor located only nine miles from the Atlantic Ocean. Within the harbor complex there are over 1100 facilities including over 720 piers, wharves and docks (many inactive), good deep-water anchorages and an extensive channel network. The following discussion of facilities is limited to the major military and commercial piers and those piers which are occasionally used by the Navy. Entrance to the harbor is via a narrow man-made channel which is difficult to navigate during heavy weather. The port facilities are discussed under three second-level subparagraphs as follows:

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\*The western reaches of Long Island Sound, though not a part of the New York Harbor complex, will also be considered in this study.

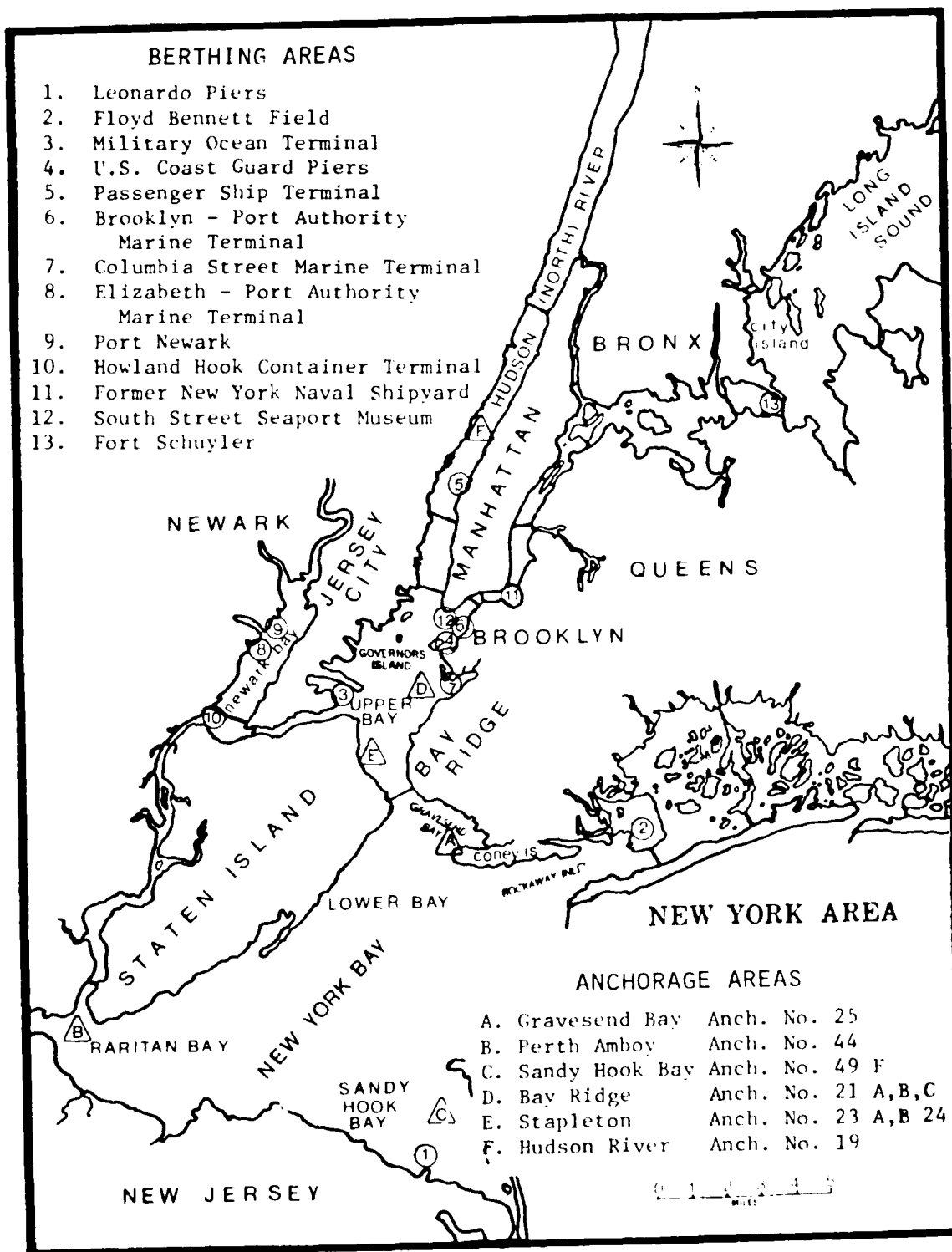


Figure XVI-1. New York Harbor, with locations of main berthing and anchorage areas.

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Figure XVI-2. Topography of New York Harbor area (elevations in feet).

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- Para. 2.1 Lower New York Bay
- Para. 2.2 Upper New York Bay, Newark Bay and Lower Hudson River
- Para. 2.3 East River and Western Long Island Sound

### 2.1 LOWER NEW YORK BAY

#### 2.1.1 Leonardo Piers, Naval Weapons Station (NWS), Earle, New Jersey

The Leonardo Piers, NWS at Earle, New Jersey are located on the southern shore of Sandy Hook Bay about 6 1/2 miles from the entrance of Sandy Hook Channel.

#### 2.1.2 Floyd Bennett Field

Floyd Bennett Field Wharf, located in Jamaica Bay, is operated by the National Ocean Survey, NOAA.

### 2.2 UPPER NEW YORK BAY, NEWARK BAY AND LOWER HUDSON RIVER

#### 2.2.1 Military Ocean Terminal, Bayonne Annex

The Military Ocean Terminal, Bayonne, New Jersey, (Figure XVI-3) is located on the western side of the Upper Bay about 15 miles from the entrance to Ambrose Channel. There are ten northside (N1 through N10), seven southside (S1 through S7) and two east side (E1, E2) berths located around the terminal peninsula.

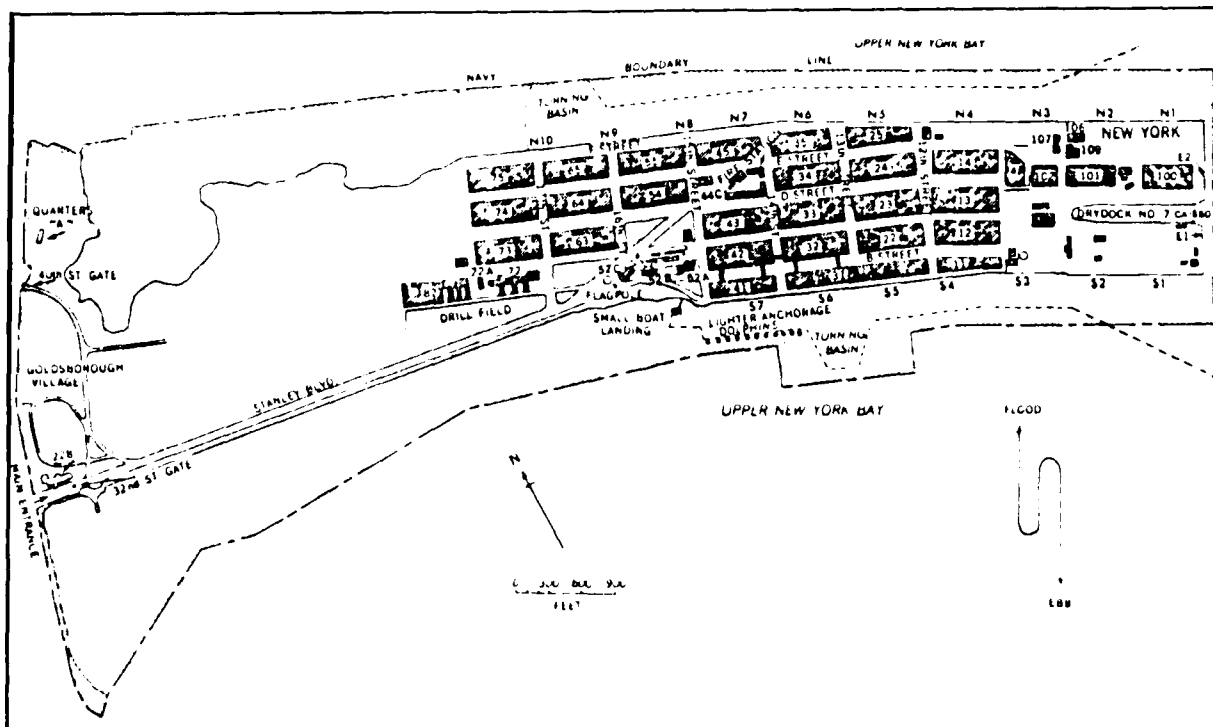


Figure XVI-3. Military Ocean Terminal, Bayonne Annex

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Northside berths are 570-633 ft long and 29-39 ft deep below mean low water (MLW). E1 and E2 are 400 and 650 ft long, respectively, and 45 ft in depth below MLW. (Note: access to the terminal is restricted to 38 ft depth below MLW.) The south side berths are 28-37 ft deep below MLW and 600-800 ft long; deck heights are 13 ft above MLW. The southern and eastern berths are somewhat exposed to incoming seas through the Narrows.

### 2.2.2 U.S. Coast Guard Piers, Governors Island

The Coast Guard Piers are located on the east side of Governors Island in Buttermilk Channel.

### 2.2.3 Passenger Ship Terminal (City of New York)

The Passenger Ship Terminal is located on the east side of the Hudson River from 47th to 54th Streets. There are four large piers (Pier Nos. 88, 90, 92 and 94) which are used primarily for mooring cruise vessels. There are a total of eight berths 775-1100 ft long constructed with timber piles and concrete decks. Deck height is 10 ft above MLW with depth alongside 28-32 ft below MLW. Piers are well protected from strong E-W winds.

### 2.2.4 Brooklyn - Port Authority Marine Terminal (Figure XVI-4a) (Owned by Port Authority New York/New Jersey)

Piers 1 and 12 of this marine terminal, which are located on the east side of Buttermilk Channel (Pier 12) and the east side of the East River entrance (Pier 1), are general cargo and container terminals and are occasionally used by Navy ships. There are six berths 300-1091 ft long, all with 32 ft depth below MLW. Pier 1 is timber pile, concrete deck with deck height 12 ft above MLW. Pier 12 is asphalt-surfaced solid fill with timber pile and concrete deck extensions - also 12 ft above MLW.

### 2.2.5 Columbia Street Marine Terminal (Figure XVI-4b) (Port Authority New York/New Jersey)

Columbia Street Pier is a semi-protected, deep-draft (35 ft below MLW) pier located in Gowanus Bay (east side Upper New York Bay). Total usable berthing space is 1250 ft on the west side of the pier and 1206 ft on the east side. This is a large, asphalt-surfaced, timber-pile pier.

### 2.2.6 Elizabeth - Port Authority Marine Terminal (Port Authority New York/New Jersey)

Port Elizabeth is a major commercial terminal for container and general cargo located on Newark Bay with access from Upper New York Bay via Kill Van Kull. The pier, which is operated by several private companies, is constructed of concrete retaining wall and solid fill with asphalt surface on concrete relieving platform. There is extensive berthing area available with 26 berths (even numbered 50 through 98) and near 16,000 ft of usable berthing space. The deck height is 12 ft above MLW and depth alongside are 35-42 ft below MLW.

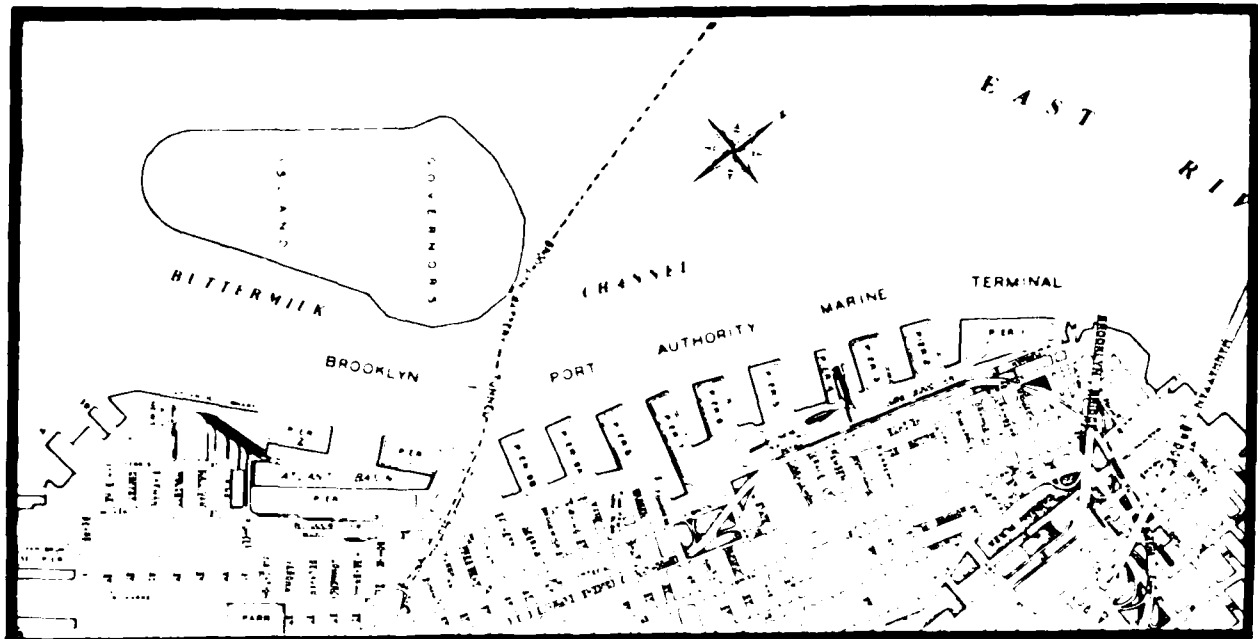


Figure XVI-4a. Brooklyn Port Authority Marine Terminal piers.

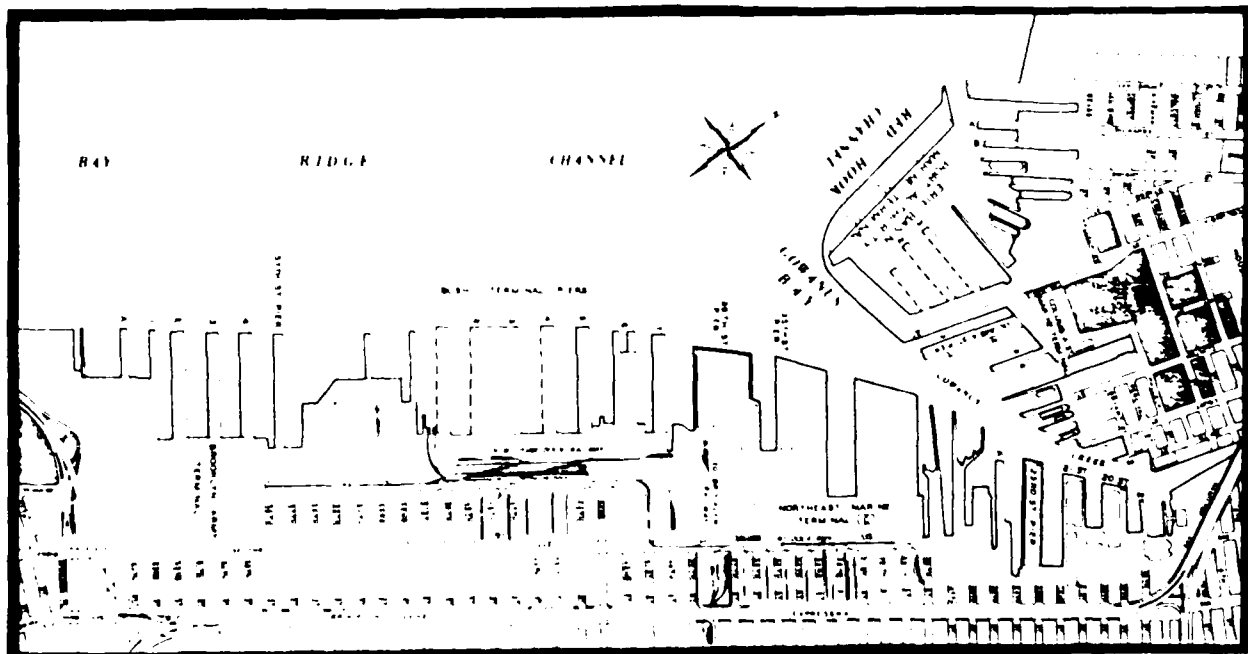


Figure XVI-4b. Columbia Street Marine Terminal.



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### 2.2.7 Port Newark (owned by City of Newark)

This terminal is similar to Port Elizabeth in construction and function and is located adjacent to Elizabeth in Newark Bay. A major marine terminal, Port Newark has a total of 37 berths with nearly 23,000 ft of berthing space. Deck height is 11 ft above MLW and depth alongside is 35 ft below MLW. Access to Ports Elizabeth and Newark via Kill Van Kull requires passage under Bayonne Bridge with a minimum clearance of 151 ft.

### 2.2.8 Howland Hook Container Terminal (City of New York)

Howland Hook is located on the northwest side of Staten Island at the southern end of Newark Bay on the northern terminus of Arthur Kill.

## 2.3 EAST RIVER AND WESTERN LONG ISLAND SOUND

### 2.3.1 Former New York Naval Shipyard, Brooklyn

The former New York Naval Shipyard is located 1.7 miles northeast of the Battery on the Brooklyn side of the East River in Wallabout Basin. There are three piers: G, J, and K. These piers are owned by the City of New York and operated by Seatrain Shipbuilding and Coastal Drydock and Repair Corporation as mooring piers for outfitting and repair. There are a total of 10 berths 350-390 ft long, with 10 ft deck height and 25-40 ft depth alongside at MLW. The channel is dredged to 40 ft up to the shipyard, but the current in the East River is strong and congestion is heavy; caution should be exercised in navigating this river. Access to the piers requires passage under the Manhattan Bridge (suspension open with a clearance of 134 ft) and the Brooklyn Bridge (suspension span with a clearance of 127 ft).

### 2.3.2 South Street Seaport Museum (Owned by City of New York)

The Seaport Museum is located on the west side of the East River about one mile northeast of the Battery.

### 2.3.3 Fort Schuyler (U.S. Government owned)

Fort Schuyler is located on the outer end of Throgs Neck Peninsula at the extreme western end of Long Island Sound. There are two wharves here.

## 2.4 NEW YORK HARBOR MISCELLANEOUS AND SMALL CRAFT FACILITIES

Within a 25 mile radius of the Statue of Liberty there are more than 150 miles of waterfront including numerous bays and interconnecting waterways. Jamaica Bay (via Rockaway Inlet) is a large bay (11 x 3.5 miles) used extensively by pleasure craft. Sheepshead Bay, north of Rockaway Inlet, is well protected and used by numerous pleasure and fishing craft. Great Kills Harbor, a shallow bight on the south side of Staten Island, is an enclosed anchorage used by small craft.

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Eastchester Bay in western Long Island Sound is used by numerous small craft, but caution must be used as the shores are fringed with boulders and there are many shoals. Manhasset Bay (western Long Island Sound) offers excellent shelter for vessels with 12 ft or less draft. Oyster Bay on the north shore of Long Island provides good anchorage for small craft.

There are numerous other small bays and inlets which could offer protected anchorages for small craft. Small, enclosed bays which offer protection from both wind and sea as well as good holding for anchors should be considered only after checking with knowledgeable local seamen.

### 2.5 CHANNELS

The principal entrance into New York Harbor is via Ambrose Channel into Lower Bay and then through Anchorage Channel (an extension of Ambrose) to the Upper Bay. Hudson River Channel continues northward from the Battery for about five miles to West 14th Street, Manhattan. Project depth for these channels is 45 ft.

The Lower Bay may also be entered through Sandy Hook Channel, which leads to berths in the western and southern portions of the Lower Bay. Sandy Hook Channel has a project depth of 30 ft. Terminal Channel, with project depth 35 ft, leads from Sandy Hook Terminus to Leonardo Piers. Chapel Hill Channel leads from Sandy Hook Terminus back to Ambrose off Loney Island at a project depth of 30 ft.

Bay Ridge, Red Hook and Bittern Milk Channels in the Upper Bay, skirt the western shores of Long Island from Bay Ridge to East River at controlling depths of 32 to 40 ft. New York and New Jersey Channels lead, via Kill Van Kull, to Newark Bay, thence via Arthur Kill around Staten Island at a project depth of 35 ft.

Long Island Sound Approach to Throgs Neck, then East River to Upper Bay, has a minimum depth of 35 ft.

### 2.6 REFERENCES AND CHARTS

The following publications and charts provide detailed information on New York Harbor and its facilities:

DMA Hydrographic/Topographic Center, 1979: Publication 940, Chapter 1, Fleet Guide New York.

U.S. Department of Commerce, 1979: United States Coast Pilot 2, Atlantic Coast, Cape Cod to Sandy Hook.

United States Government Printing Office Washington, 1963: Corps of Engineers, USA, Port Series No. 5 - The Port of New York, NY, and NJ.

U.S. Department of Commerce, chart Nos. 12327 (New York Harbor), 12334 (New York Harbor - Upper Bay and Narrows), 12335 (Hudson and East Rivers), 12336 (East River - Lallan Island to Queensboro Bridge), 12361 (Long Island Sound - Western Part), 12341 (Hudson River-Days Pt. to George Washington Bridge), 12350 (Jamaica Bay and Rockaway Inlet).

## NEW YORK, NY

### 3. HEAVY WEATHER CONSIDERATIONS

#### 3.1. NEW YORK NEW JERSEY HARBOR AREA

The New York New Jersey harbor area is one of the world's largest commercial port areas. Pilot and tug services are considered some of the best in the world. Tug availability is excellent with several large commercial firms available. Pilotage is not compulsory for U.S. Naval ships entering New York Harbor, but pilotage is recommended for all large ships. Sandy Hook Pilots will pilot ships from the Atlantic, while Hell Gate Pilots (members of N.Y.-N.J. Long Island Pilots Association) will pilot ships inbound/outbound through Long Island Sound. See current Fleet Guide New York or Coast Pilot-2 for regulations, weather, pilots and other information.

#### 3.2. NEW YORK HARBOR AREA

New York is considered to be a protected harbor except in the rare event of the hurricane that makes a direct landfall from the open ocean nearby. Semi-protected deep-water anchorages and the availability of many excellent berthing facilities -- which in many cases are protected by both natural geological features and man-made structural features -- dictate that the safety of ships will be more assured in selected New York pier berths than at sea or at Long Island Sound anchorages.

Consideration of berthing space involves such variables as accessibility, protection afforded, berthing size and alongside depth as well as contention for space with commercial vessels. With hundreds of piers, wharves and docks in the New York New Jersey port complex, evaluation of suitable berths has necessarily been restricted to the major military piers, to the major commercial piers, and to those piers which are occasionally used by the Navy. A detailed evaluation of berthing piers and anchorages is given in Para. 5.3, "Remaining in Port."

#### 3.3. HURRICANE PLAN AND PREPARATION

Commander, Naval Base Philadelphia, is the area coordinator for disaster preparedness planning and operations. NAVSTA NY Instruction 3140.1 is the destructive weather Plan which will be executed by Naval Station New York, in the event of forecast or existing heavy weather in New York Harbor. NAVSTA NYINSI 5450.10, SOPA (ADMIN) sets forth the rules and regulations for visiting ships in the New York Harbor area.

Upon notification by Commander, Naval Base Philadelphia, that storm conditions are being set, the Commanding Officer, Naval Station New York, will issue the appropriate weather condition messages to all naval commands and activities within the New York Harbor area. NAVSTA NYINSI 5450.10 provides heavy weather guidance for ships within New York Harbor area.

#### 4. TROPICAL CYCLONES AFFECTING NEW YORK HARBOR

##### 4.1 CLIMATOLOGY

A tropical cyclone threat is defined as any tropical cyclone approaching within 180 n mi of the New York Harbor complex. Some storms passing outside this radius, however, may still have considerable effect upon the harbor. Information on Atlantic tropical cyclones which passed near New York Harbor is available back to the year 1871.

The data used to generate approach direction, strike probabilities and time to closest point of approach (CPA), which are shown in Figures XVI-6 through XVI-10 were extracted from the 109-year period 1871-1979. A shorter period of 94 years, 1886-1979, was used to construct the seasonal information depicted in Figure XVI-5 (storm center wind information was not available until 1886).

Historically, tropical cyclones can occur in the North Atlantic in any month of the year. With the exception of a tropical cyclone in December 1925 and one in February 1952, however, all recorded threats to New York Harbor occurred from June through November.

Figure XVI-5 is a monthly summary of tropical cyclone threat occurrences for the harbor area. An average of 0.82 tropical cyclones per year, or about 4 in each 5 years, pass within 180 n mi of New York Harbor. Forty percent of these (.33 per year, or 1 every 3 years) were at hurricane strength while within the 180 n mi radius.

For the 109-year period 1871-1979, a total of 88 tropical cyclones have threatened New York Harbor.\* Peak months of threat are August and September, with 65 percent (57 of 88) of all tropical cyclones and 81 percent (28 of 34) of all hurricane (winds >63 kt) threats occurring in those two months.

Figure XVI-6 shows the directions by compass octant from which tropical cyclones approach the New York Harbor area. The most frequent threat is from tropical cyclones that approach from the south and southwest. The normal path for a tropical cyclone, once it has reached the latitude of New York Harbor, is one of recurvature toward the northeast. This, when combined with the land shape of the eastern seaboard of the United States, dictates that most storms either make landfall well to the south of New York Harbor -- thus losing intensity prior to threatening New York -- or pass clear offshore to the east.

On rare occasions, however, unusual weather patterns can force tropical cyclones to adopt a northerly or northwesterly path, which may lead them to make a direct landfall from the open ocean near New York. The disastrous New England hurricane of September 1938 is a notorious example, and Hurricane Carol of 1954 closely approached this situation. These intense storms passed to the east of

\* Total threats to New York Harbor actually were 89: One looping storm in 1961, Ester, posed two threats -- the first on September 21 and the second on September 25.

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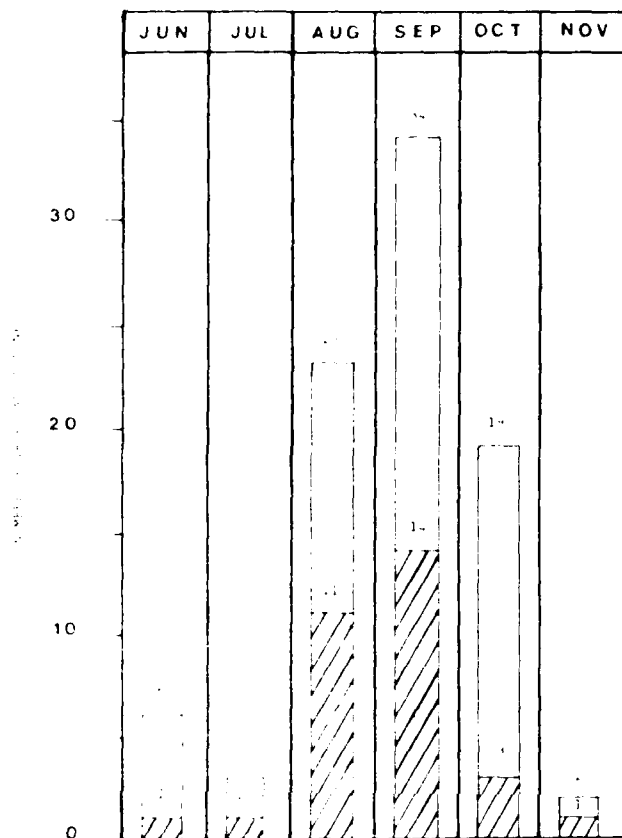
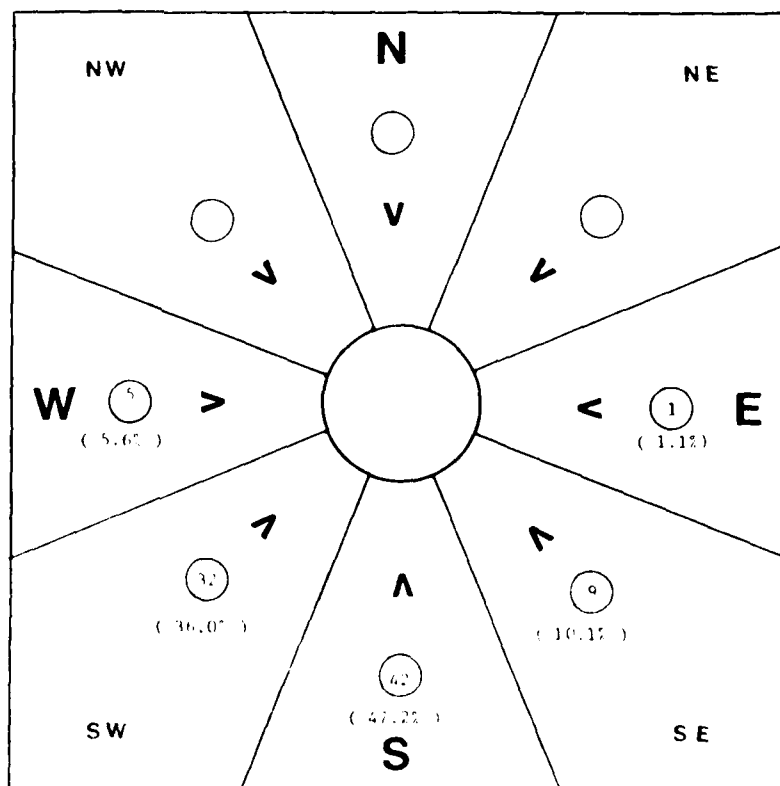


Figure XVI-5. Seasonal distribution of tropical cyclones passing within 180 n mi of New York Harbor, June-November (based on data from the period 1886-1979). Monthly totals shown above each column; numbers of threats of hurricane intensity are shown by hatched areas. (This figure does not depict two non-seasonal tropical cyclones of December 1925 and February 1952.)

Figure XVI-6. Directions of approach of tropical cyclones that passed within 180 n mi of New York Harbor during the period 1871-1979. Numbers of storms approaching from each octant are circled; percent figures are percentages of total sample approaching from that octant.



New York Harbor, however, and thus the harbor was on the safe semicircle (less dangerous side) of the storm.

Perhaps the most destructive hurricane on record to affect New York Harbor was the September 1821 storm. Reliable meteorological records are not available, but it is thought that it made its first landfall well to the south of New York. Eyewitness accounts and press reports indicate the storm center passed across extreme western Long Island with landfall near Jamaica Bay.

The September 1938 hurricane was most destructive to the south shore of Long Island. Winds to 54 kt with gust to 70 kt were recorded at Central Park. Storm surge raised water levels 3.4 ft above predicted tides at the Battery and 7.3 ft above predicted tides at Willets Point.

Figures XVI-7 through XVI-10 are statistical summaries of threat probabilities based on tropical cyclone tracks for the years 1871-1979.\* The shapes of the threat probability envelopes in the annual summary of Figure XVI-7 point out the path of those storms that most frequently threaten the New York Harbor area. This path extends from the generating area in the main basin of the tropical Atlantic north of the Greater Antilles, along the East Coast through the Cape Hatteras area, and then parallel to the upper New England coast between Cape Hatteras and Cape Cod. Within the 180 n mi radius of New York Harbor, the majority of storms remain at sea and pass south-southeast of the harbor.

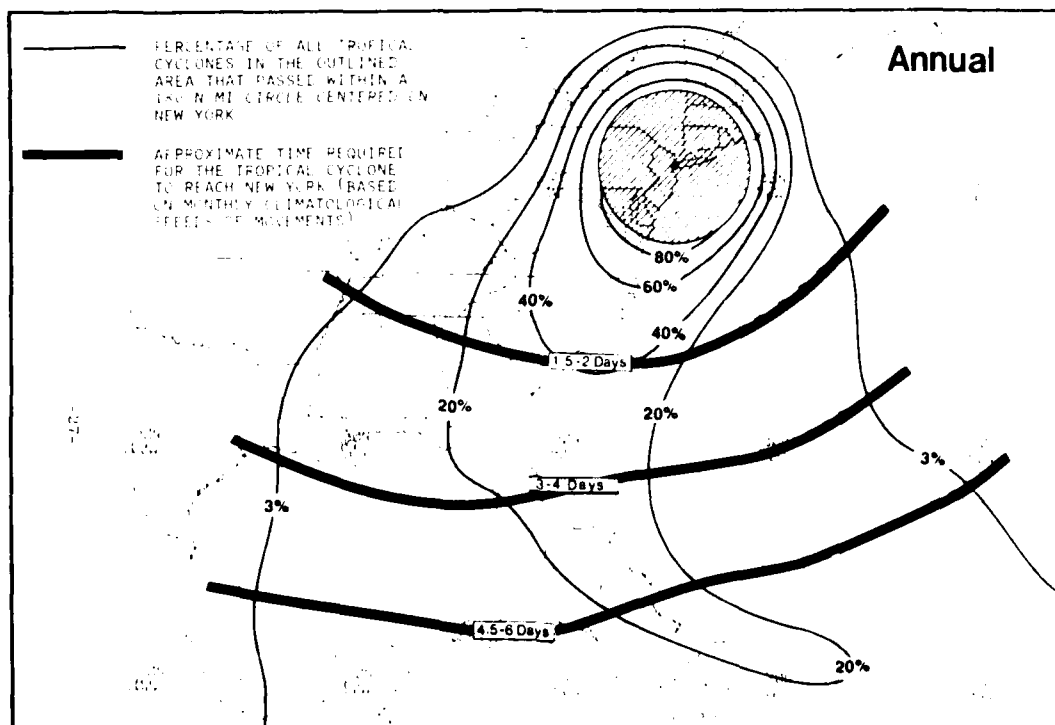


Figure XVI-7. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi (shaded circle) of New York Harbor, based on data from 1871-1979.

\*Track information obtained from National

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Figures XVI-8 through XVI-10 indicate some seasonal variations in principal threat directions. (Light lines show percent threat to the area encompassed by the 180 n mi circle centered at New York Harbor. Heavy lines show approximate time to CPA.)

Speed of movement can vary widely from storm to storm. For example, the September 1938 hurricane cut the "average" predicted climatological time in half as it moved from a position due east of southern Florida to the New York area in less than 30 hours. Rapid movement such as occurred with this storm not only decreases warning and preparation time, but increases the chances of the storm's being more intense upon arrival as the forward movement adds to the speed of the winds in the dangerous right semicircle of the storm.

The months of July and August are the start of the major hurricane season. Twenty-six of the 88 storms (about one-third) occurred during these two months. The primary threat path is that described by Figure XVI-7, but a secondary threat exists from the Gulf of Mexico area with approach from the southwest overland through South Carolina and Virginia (Figure XVI-8). The source region for most of these secondary threat storms is the western Caribbean.

September has been known historically as the month of hurricanes (Figure XVI-9). Close to 40% (34 out of 88) of the tropical storms to affect the harbor occurred in this month. Tropical cyclone paths to New York during September contrast with July and August paths, in that they more closely follow the Gulf Stream and fewer make landfall along the East Coast. The great majority of the September storms (29 out of 34) remained at sea well to the southeast of New York. Four of these, however, crossed over the eastern portion of Long Island and one, the 1821 storm, passed just east of the harbor. They were some of the most destructive storms on record at New York Harbor.

The period October through June (Figure XVI-10) covers nine months and only about one-third of the tropical cyclones that affected New York Harbor. The majority of the paths have been from the Gulf of Mexico through the panhandle of Florida, then overland paralleling the Eastern Seaboard. For the period 1886-1979, only four off-season tropical cyclones reached New York while still maintaining hurricane intensity at CPA during these months (3 in October, 1 in November).

For all months of the 94-year period, 1886-1979, 31 tropical cyclones were at hurricane strength ( $\geq 64$  kt) while within the 180 n mi radius of New York Harbor. Of these 31 hurricanes, 25 passed to the east, 3 went to the west, and 3 passed basically to the south of the harbor. Speeds of approach for typical tropical cyclones vary from 10-15 kt while in the tropics, but up to 25-30 kt near the New England Coast.

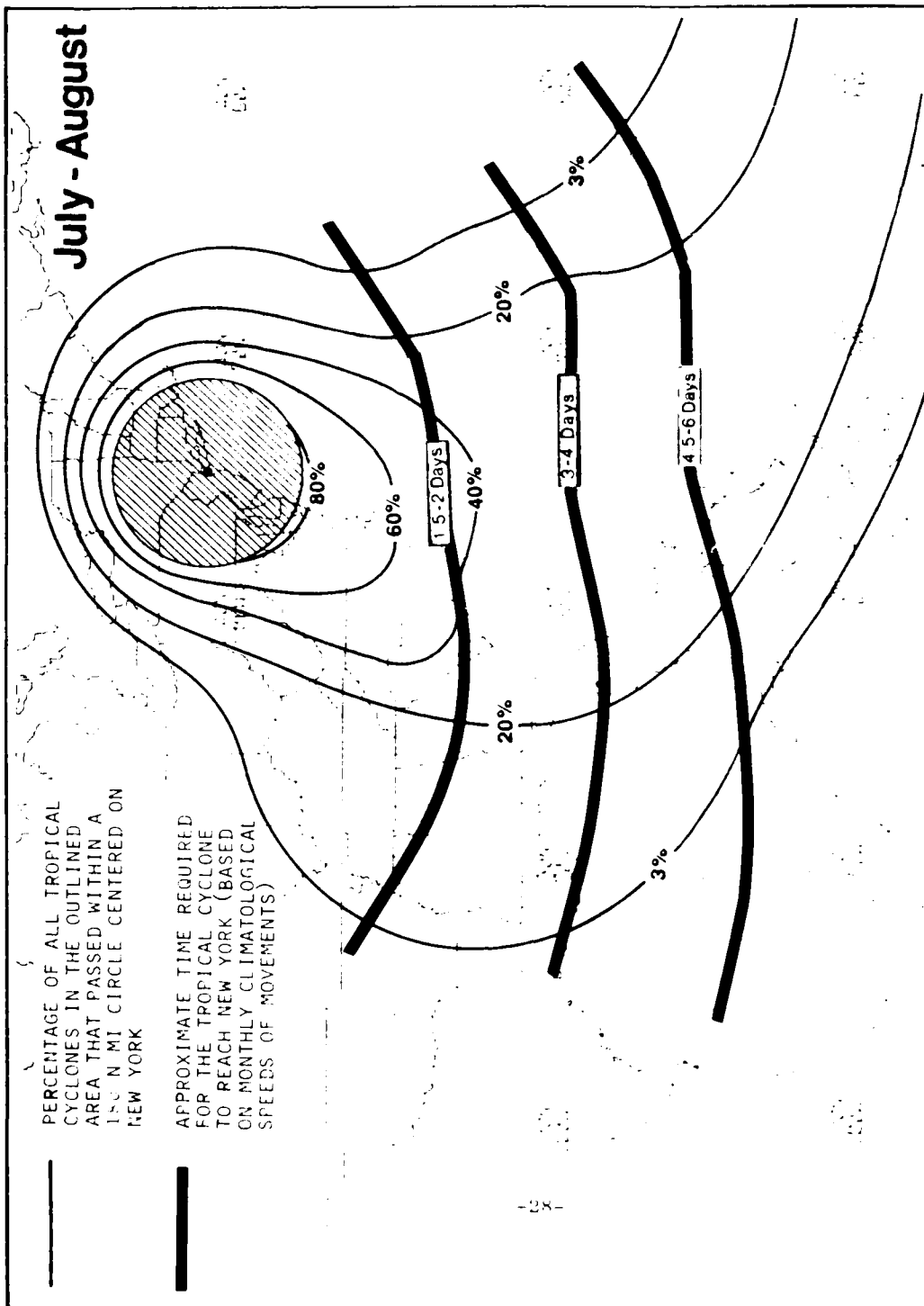


Figure XVI-8. Probability that a tropical cyclone will pass within 180 n mi of New York Harbor (shaded circle), and approximate time to reach closest point of approach, during July and August (based on data from 1871-1979).



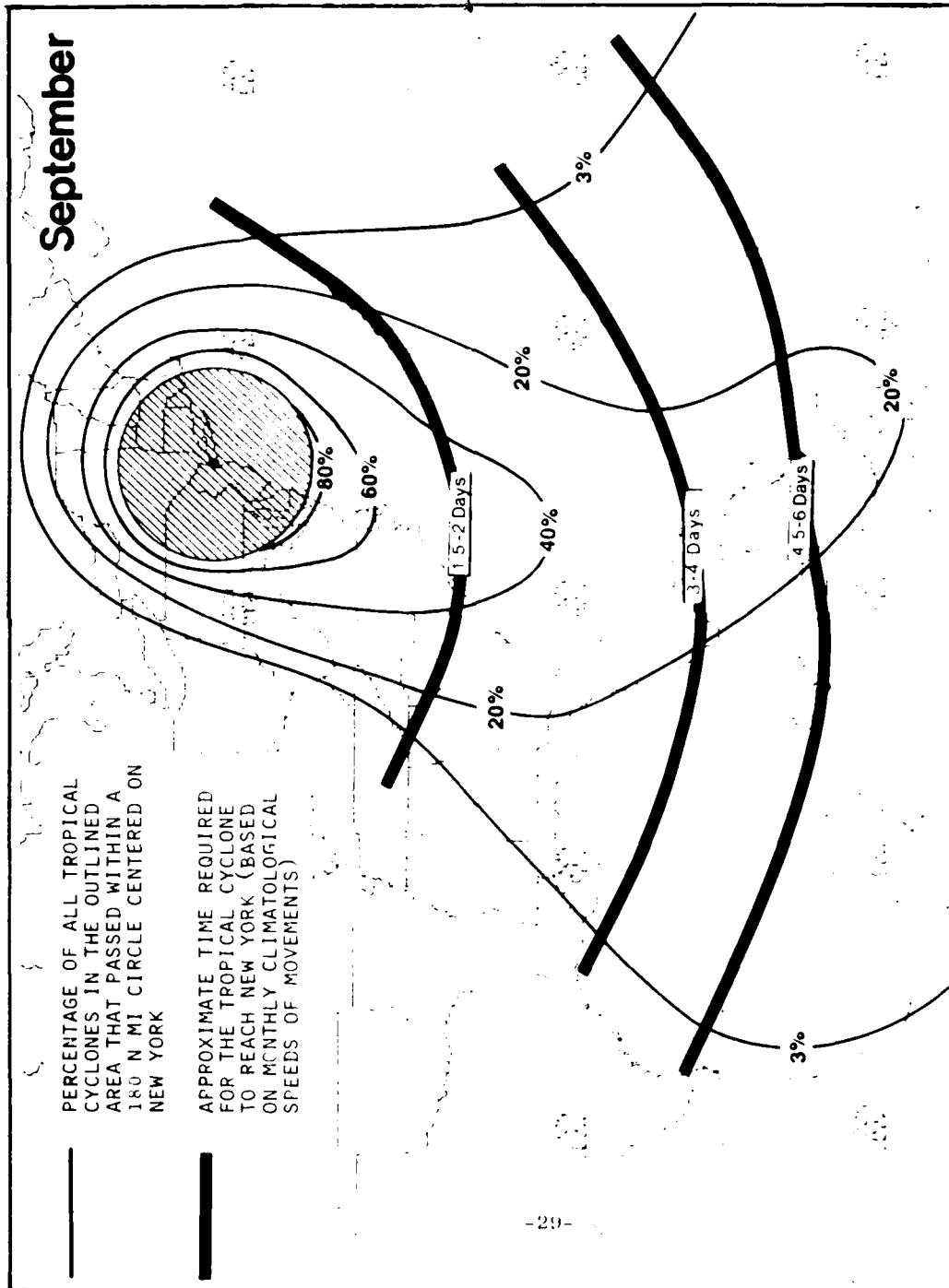


Figure XVI-9. Probability that a tropical cyclone will pass within 180 n mi of New York Harbor (shaded circle), and approximate time to reach closest point of approach, during September (based on data from 1871-1979).

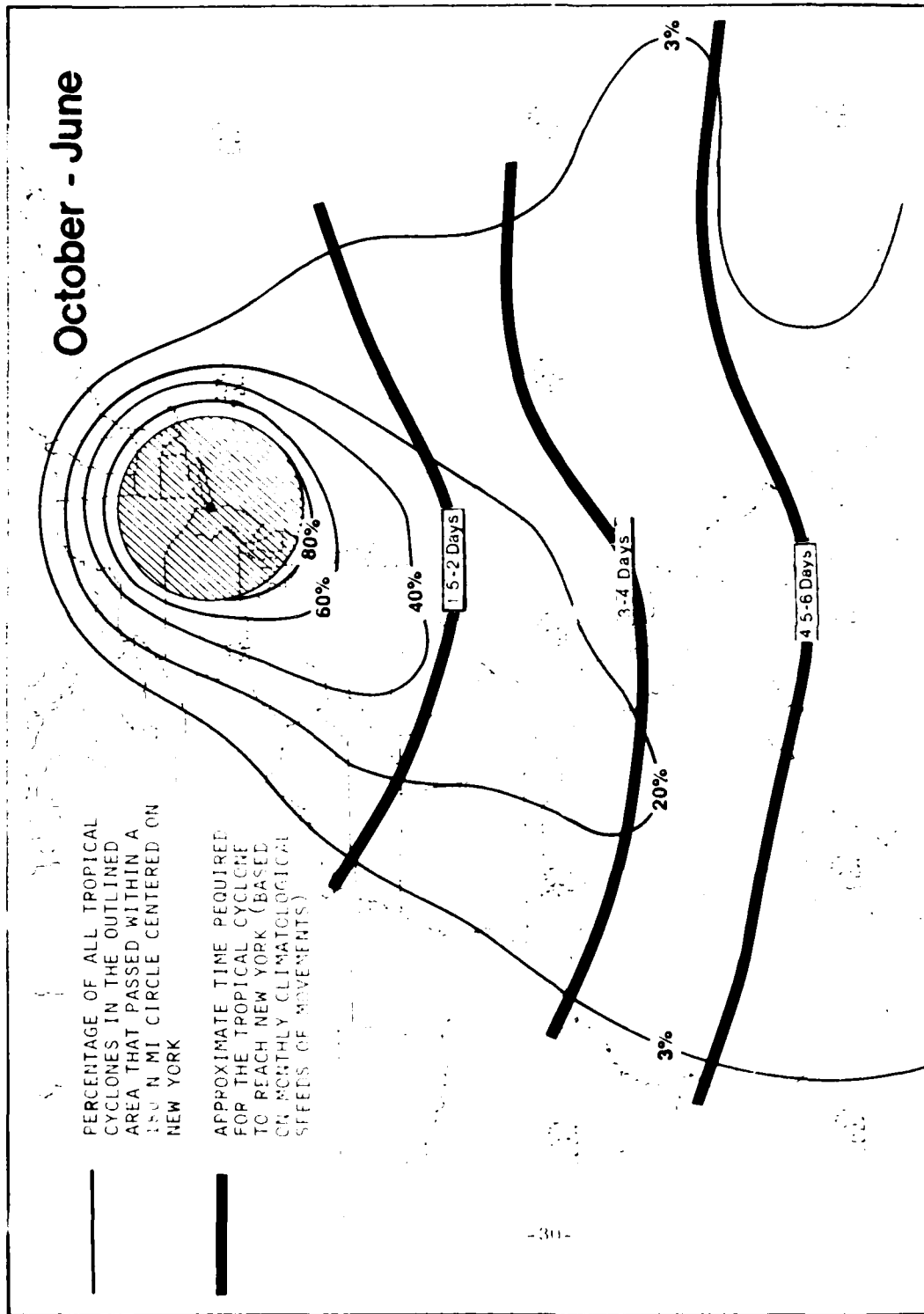


Figure XVI-10. Probability that a tropical cyclone will pass within 180 n mi of New York Harbor (shaded circle), and approximate time to reach closest point of approach, during October through June (based on data from 1871-1979).

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### 4.2 WINDS AND TOPOGRAPHICAL EFFECTS

Wind records for the New York Harbor area date back to 1869 when wind and temperature recordings were made in Central Park; accurate hurricane wind data from this site first became available from 1893. Wind records for this study were collected from five sites including Central Park. The sites were selected to provide both exposed and relatively sheltered locations and to ensure a continuous record of data over the years of interest. Some sites had broken periods of recorded data. Locations (Figure XVI-11a) and years of coverage were:

- |                             |                      |
|-----------------------------|----------------------|
| (1) Central Park, NY        | 1893-1979            |
| (2) Sandy Hook, NJ          | 1914-1945, 1966-1979 |
| (3) Floyd Bennett Field, NY | 1941-1970            |
| (4) La Guardia Field, NY    | 1939-1979            |
| (5) Newark, NJ              | 1931-1979            |

Examination of the records from these sites revealed that only one storm produced sustained hurricane force winds ( $\geq 64$  kt) in the New York Harbor area from 1893 to 1979. The 14 September 1944 hurricane produced sustained winds that were recorded at 64 kt in Central Park and 70 kt at La Guardia Field. The more exposed site at Sandy Hook, NJ, recorded near hurricane velocity at 63 kt.

Other hurricanes that caused considerable damage in the harbor area were the storms of 3 September 1821, 21 September 1938, 30 August 1954 (Carol) and 12 September 1960 (Donna). Figure XVI-11a illustrates the paths of these storms through the New York Harbor area and shows the locations of the recording sites. Table XVI-1 is a comparison of the recorded wind strengths at these sites for the four major storms of the period 1893-1979.

Table XVI-1. Recorded wind strengths at New York for the four most destructive hurricanes on record (1893-1979).

Storm	CPA* (n mi)	Storm Max Wind at CPA (kt)	Winds (Sustained/Gusts, in kt)				
			Central Park	Sandy Hook	Floyd Bennett Field	La Guardia Field	Newark N.J.
21 Sep 1938	110	85	54/61	43/49	-	-	42/-
14 Sep 1944	60	75	64/70	63/78	50/-	70/93	48/74
30 Aug 1954	60	85	40/42	-	35/45	45/60	37/48
12 Sep 1960	60	90	49/53	-	34/55	55/84	38/50

\*CPA - Closest Point of Approach of storm center to 40.7N latitude, 74.0W longitude.

Figure XVI-11b depicts the track segments of tropical cyclones that occurred during the period 1945-79 and resulted in strong winds ( $\geq 27$  kt) at La Guardia Field, NY. The dotted segments of the tracks depict center

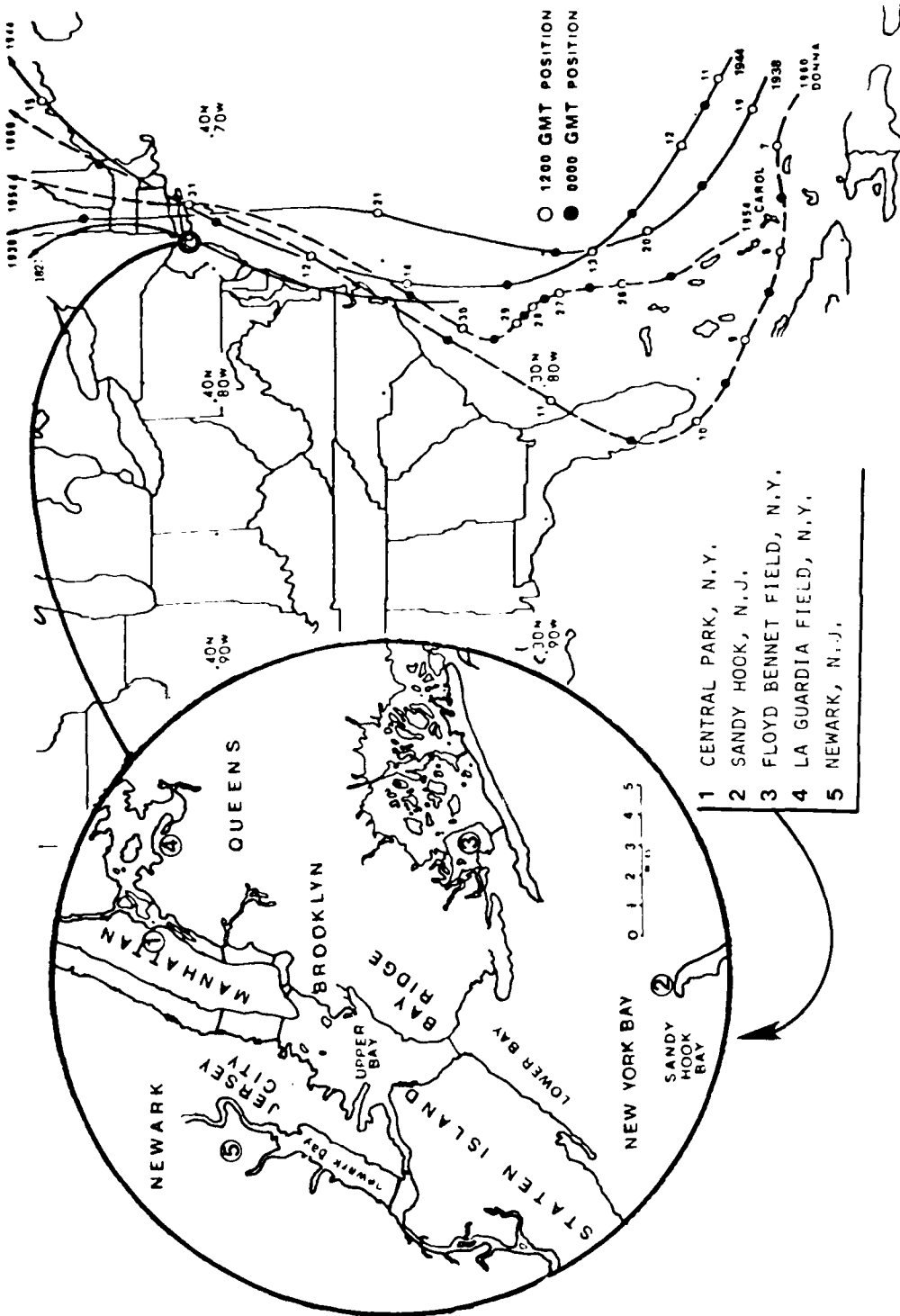


Figure XVI-11a. Tracks of hurricanes that caused considerable damage in the New York Harbor area, with meteorological stations identified in inset.

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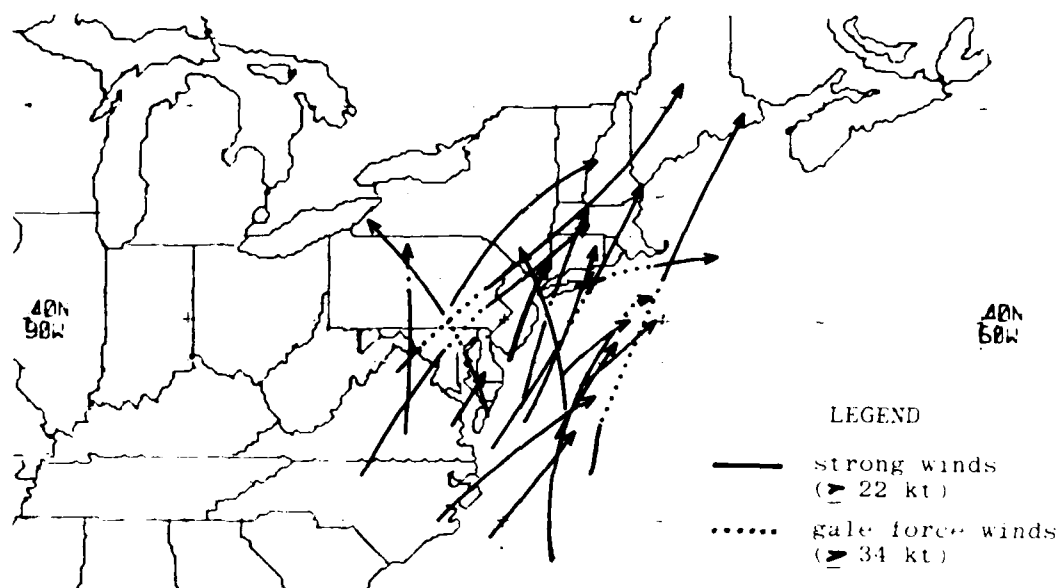


Figure XVI-11b. Positions of tropical cyclone centers when strong winds and gale force winds (see figure legend) occurred at La Guardia Field, NY, (1945-79).

positions where the storm caused gale force winds at La Guardia Field. The majority of these tropical cyclones were moving on a track from SSW to NNE through the area. Gale force winds occurred mainly while the tropical cyclones were southeast or southwest of the harbor. Gale force winds occurred with centers as far as 240 n mi away.

Topographical features will dictate to a great extent the amount of wind protection at any one particular site in the New York Harbor area. Wind protection is also offered by the massive buildings that surround much of the New York Harbor area. The combined effect significantly reduces the forces of strong winds at piers or anchorages in close proximity to these features.

The Lower Bay is generally not protected from strong winds due to surrounding flat terrain to the west and south and open water to the east. Staten Island and western Long Island offer some protection to the north. Sandy Hook Bay is exposed from all quadrants. Raritan Bay, in the extreme western reaches near Perth Amboy, is somewhat protected from north-south winds but exposed to east-west winds.

Upper Bay, though somewhat protected, has enough fetch for considerable damage from wave action in strong winds, especially from a wind set from a northwest direction that sweeps across the flat areas of Newark Airport and Bayonne Peninsula. This was demonstrated by the 21 September 1938 storm, where

strong winds from the northwest battered piers, bulkheads and berthed craft (primarily barges) along the eastern side of the harbor at the Brooklyn Bay Ridge section.

Some caution should be used when assessing the value of particular berths or anchorages during a hurricane threat. Some may offer good protection from strong wind/wave action from a particular direction. However, the tight, cyclonic circulation and storm movement typical of tropical cyclones can cause a sharp change in wind direction and can change a protected position into an exposed position. The predominant direction of the strongest winds associated with past major storms moving through the harbor area has been from the west through north quadrant.

The lower Hudson River is well protected by the higher terrain and structures to the east, and the New Jersey Palisades to the west. There is a narrow window of exposure to north-south winds. The western reaches of Long Island Sound are generally not well protected from high winds except in some areas of semi-enclosed bays such as Manhasset and Oyster Bays.

#### 4.3 WAVE ACTION

Lower Bay is subject to wave action due to an open quadrant, east through south, to the Atlantic. The size and depth of the bay also provide sufficient fetch for a strong wind to generate destructive waves. Deep ocean swell approaching from the open quadrant would be reduced by shoals at the entrance to Lower Bay between Sandy Hook and Rockaway Point.

Upper Bay, Newark Bay, lower Hudson River and East River are subject to limited wave action due to the small generating area afforded to the wind. However, strong winds have generated enough combined wind/wave action to cause considerable damage in the Upper Bay (Para. 4.2).

Long Island Sound is a deep water sound with generous fetch in an east-west direction (>100 n mi). North/south fetch is limited to about 20 n mi at the widest point. Either is sufficient to permit substantial damage from waves in strong winds.

#### 4.4 STORM SURGE AND TIDES

Storm surge and astronomical tidal conditions can combine to greatly increase the danger and damage associated with a major storm. Storm surge (an abnormal rise of water generated by a hurricane), when combined with a normal local high tide, can inundate coastal areas. This combination also provides a high water level upon which wind waves may ride to cause severe destruction to those areas not normally subjected to wave action. Combined storm surge and tide have produced high water levels of over 10 ft above MLW in the New York

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Harbor area during major hurricanes and levels greater than 15 ft above MLW in western Long Island Sound. Figure XVI-12 shows recorded hurricane-induced high water marks at several sites in the New York Harbor area and western Long Island Sound for two major hurricanes that made landfall in the area at or near astronomical high tide.

Those recorded hurricanes that caused major damage in the New York harbor area passed east of the harbor (refer to Figure XVI-11a) and generated substantial storm surge. The most significant differences among the inundations associated with these storms were the timing of their arrivals in relation to the local astronomical tides. The storms of 1821 and 1944 arrived at or near low tide, and the storms of 1938, 1954 and 1960 arrived at or near high tide.

### 5. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions to Navy ships for dealing with destructive weather in the New York Harbor area are found in the SOPA Manual (NAVSTA NYINST 5450.1), for New York. This document describes hurricane readiness conditions and the appropriate actions to be taken. The Department of the Navy considers New York a protected harbor except in the most severe weather. Ship safety is considered to be more assured at suitably protected New York Harbor berths than at sea or at Long Island Sound anchorages.

It is further recommended that ships moored at their normal berths after Hurricane Condition Two (hurricane force winds within 24 hours) has been set, should consider making thorough preparations for securing at these berths rather than risk being caught in strong winds during close-quarters maneuvering for alternative berths.

The decision to evade at sea or remain in port must be based on several factors:

#### (1) Expected Weather Conditions

- Forecast track of the hurricane relative to the port
- Size and strength of the storm
- Speed of approach
- Forecast storm surge, tides and sea states

#### (2) Harbor Characteristics

- Topography of the surrounding terrain as to providing wind/wave shelter
- Quality and locations of moorings and piers
- Anchorage holding qualities
- Currents and maneuvering room
- Harbor congestion

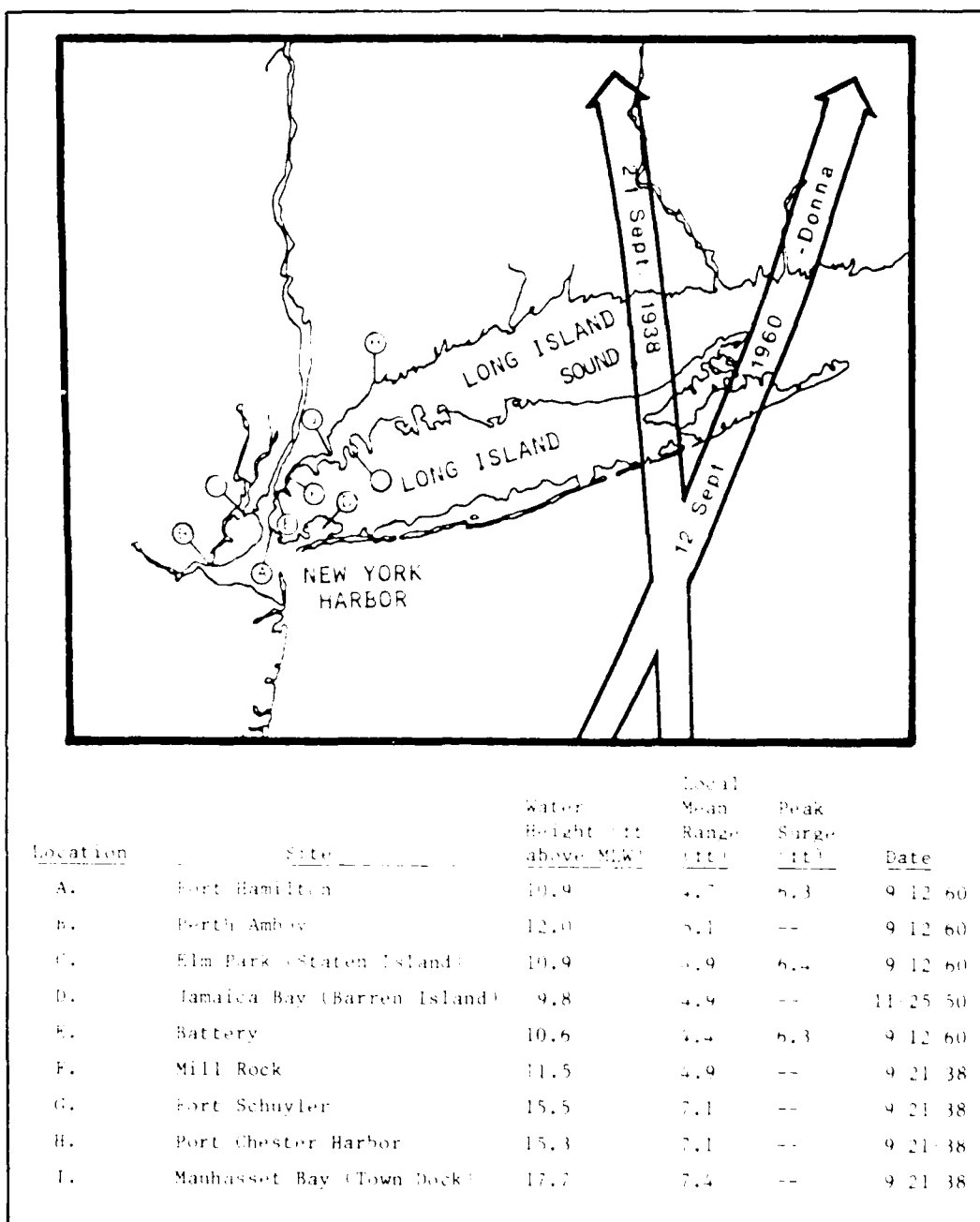


Figure XVI-12. High water marks recorded in the New York Harbor area.



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### 3. Ship's Characteristics

- speed, seaworthiness and ability to maneuver in heavy seas
- ship's relative ability to withstand adverse weather at anchor, moored or docked alongside
- overall condition of ship and crew

### 4.1. EVASION RATIONALE

A ship may choose to evade at sea in the event of a threatened hurricane strike at the port, dictated by some of the considerations discussed in this subsection. The ship's command, however, must consider that (1) New York Harbor provides a semi-protected environment with excellent berthing facilities, and (2) that all factors considered, ship safety is more assured in protected berthing within the harbor.

A ship's captain must make a decision to evade at sea or remain in New York Harbor at a point in time (36-48 hours prior to destructive force winds) when there is a low probability that the hurricane will actually strike the harbor. The forecast error for storms approaching the New York area at Hurricane Center (111 48-hour forecast) is greater than 300 n mi (as shown in Figure 1-1 of the General Guidance section of this Handbook). It should also be noted that the New York area experiences one of the lowest frequencies of hurricane recurrence of any area along the Gulf and Atlantic coasts. Further, the probability of successful evasion at sea is decreased by the high speed of advance of a major storm and the uncertainty of its path at recurvature latitudes. All of these meteorological factors support a decision to remain in harbor.

On the other hand, there is no record that the New York Harbor area ever has faced the "worst case" in which a major hurricane makes direct landfall just to the west of the port. Second, there are few berths with all-round protection from wind and wave action. Third, New York Harbor is large and congested, and the danger of damage from ships or barges adrift or major debris afloat must be considered. These three considerations warrant further discussion.

The hurricanes that severely damaged the harbor area were discussed in Section 4.2. Two facts are noteworthy: (1) All of these storms passed to the east of the harbor, placing the harbor area on the less destructive side of the storm; and (2) Maximum sustained winds in the harbor area were at hurricane strength for only one of the storms on record.

A storm with a speed of advance of 30 kt, which is not unusual for this latitude, can easily have winds 50-60 kt higher in the right semicircle. Should a hurricane with characteristics similar to those depicted in Figure XVI-11, take a path slightly more northwesterly -- which would place the New York Harbor area in its strong semicircle -- a disaster of major proportions would be quite possible.

The surrounding topography and massive buildings do offer protection in many areas. Because of a hurricane's physical makeup and unpredictability, however, major shifts in wind direction can occur during storm passage. In order to assure good protection, a barrier would have to provide a full 360 degrees of coverage. Any topographic feature can serve as a barrier to wind-waves at a given time, but it could also funnel energy if the wind shifts to a new quadrant. This could be disastrous to a ship at anchor, especially to one with marginal holding or swing room.

New York Harbor is a mixture of older berthing areas (many of them unused) and modern new container, petroleum, steamship and general terminals. While providing excellent berthing in many areas, New York Harbor also could produce major debris during a severe storm that broke up older areas of neglected waterfront. The size and complexity of the harbor area also increases the potential for ships or barges to break their moorings and become potential dangers to other vessels.

## 5.2 EVASION CONSIDERATIONS

If it is decided to evade at sea, consider the following: (1) necessary safe transit time to open ocean, (2) present position of storm, (3) storm speed of approach, and (4) most likely storm path.

Given the evasion decision, it is very important to assess the threat correctly and take quick action. Figures XVI-7 through XVI-10 show average travel time for storms to reach the New York Harbor area. The 21 September 1934 storm, however, moved from a position east of Florida ( $27^{\circ}\text{N}$ ,  $74^{\circ}\text{W}$ ) to the harbor area in 30 hours versus the 3-4 days average travel time.

Each threat must be judged on its individual merits, but historically there are two threat locations for storms that ultimately pass within 180 n mi of New York. During the 3-4 days prior to passage, the threat storms are typically located (1) east of Florida and north of the Bahamas, or (2) in the Gulf of Mexico.

### (1) East of Florida/North of Bahamas

The hurricanes that approach from this area and follow the general contour of the East Coast pose the greatest threat to the New York Harbor area. A storm east of  $75^{\circ}\text{W}$  at  $30^{\circ}\text{N}$  will pose less threat probability than one to the west of  $75^{\circ}\text{W}$ , because normal recurvature will further reduce its chances of hitting the New York Harbor area as it moves north.

There are meteorological indicators that forewarn of a bad storm in the New York/New England area: a strong recurving hurricane near the East Coast; a high pressure area or ridge in the western North Atlantic blocking recurvature; and an advancing trough of low pressure in the eastern U.S. These special synoptic

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features promote rapid acceleration into the New England area with little weakening of the storm.

Sorties should be to Long Island Sound or on a southeast heading to clear to the southeast side of the projected track of the hurricane. The sortie also must be initiated early, because the majority of the storms off the New England coast accelerate along a track in a northeasterly direction well south of Cape Cod.

### (2) Gulf of Mexico

Hurricanes that approach to within 130 n mi of the New York Harbor area from this region generally weaken during their overland passage and are not considered a major threat to the harbor.

## 5.3 REMAINING IN PORT

All ships are advised to remain in New York Harbor in the event of a forecast hurricane strike, assuming that adequately protected berthing is available. If the predicted threat is an average hurricane of moderate strength, then the recommendation is to utilize normal berths with normal hurricane precautions as outlined in NAVSTANY Destructive Weather Plan (NAVSTANY INST 3140.1).

If the storm is forecast as dangerous, with center winds well above hurricane strength -- or if the previously mentioned "meteorological indicators that forewarn of a bad storm ..." exist as synoptic features -- then the recommendation is to reberth if necessary at the most protected berth available and to take extraordinary precautions in securing. Pier height will be a primary consideration due to loss of protection at lower piers (i.e., <10 ft above MLW) with the rise of water caused by possible accompanying storm surge. Evaluation of berthing areas should also consider wind/wave protection, area congestion, and pier strength.

### 5.3.1 General Assessment of Berthing Facilities

(1) Lower New York Bay (including Sandy Hook and Raritan Bay), in general, does not afford adequate protection for berthing during a hurricane. With more than 10 miles of open water in a N-S fetch and 12 miles E-W, piers and berthed craft open to the bay could sustain substantial wind/wave damage in a major storm. Floyd Bennett Field Wharf, even though in an enclosed bay, is exposed to high winds from all quadrants due to surrounding low terrain.

(2) Upper New York Bay, Newark Bay and the lower Hudson River provide areas which, depending upon location, offer partly protected anchorages and berthing. Due to the small number of U.S. Navy ships that are in the New York Harbor area at any one time and the large number of berths available, adequate berthing availability is not considered a problem.

The Military Ocean Terminal's (Bayonne, NJ) northside berths are considered adequate except for the most severe storms. The south and east side berths are more exposed. The Coast Guard piers on the east side of Governors Island are protected except for southwest wind/wave fetch. The Passenger Ship Terminal berths on the east side of the Hudson River are well protected except for direct north-south winds. Piers 1 through 12 of the Brooklyn-Port Authority Marine Terminal are all considered adequate except for the most severe conditions.

Columbia Street Marine Terminal affords good protection in Gowanus Bay. Elizabeth and Port Newark are good storm berthing areas, but are somewhat exposed to strong east/west winds with Newark Airport to the west and the Newark Bay to the east. Howland Hook is protected by Staten Island to the east and Elizabeth to the west. (Access to these last three berths in Newark Bay is more difficult.)

(3) The East River and western Long Island Sound offer fewer adequate berths. The former New York Naval Shipyard offers excellent protection in Wallabout Basin on the East River. South Side Seaport Museum piers are somewhat protected, but are not recommended due to the presence of permanently moored vessels. Fort Schuyler, located on Throgs Neck, is not recommended during severe storms because of possible high surge (5.5 ft over current dock heights during the September 21, 1938 hurricane) and lack of protection from high winds.

Specific berths are evaluated in the following subparagraphs 5.3.2-.14:

#### 5.3.2 Leonardo Piers, Naval Weapons Station, Earle, New Jersey

The Leonardo Piers are not recommended due to their exposed position.

#### 5.3.3 Floyd Bennett Field Wharf

Floyd Bennett Field Wharf is not recommended due to the exposed position of the pier and the difficulty of access. Coast Pilot 2 lists four sunken wrecks near Rockaway Inlet entrance or in the inlet itself. The inlet is also obstructed by a shifting sandbar.

#### 5.3.4 Military Ocean Terminal, Bayonne Annex

Military Ocean Terminal, located on the western side of Upper Bay, is well protected from ocean swell and wind waves, but is somewhat exposed to winds from all except the southern quadrant. The low, flat nature of the Bayonne Peninsula and Newark Airport to the west offer little wind protection from the west. Staten Island to the south offers protection from that southerly direction. The piers are two feet above the highest recorded surge in the area (11 ft above MLW at Caven Point, 12 September 1960).

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### 5.3.5 U.S. Coast Guard Piers, Governors Island

The Coast Guard Piers are fairly well protected from both wind and seas except from a northeast or southwest direction. These piers are subject to being awash in extremely high surge because of their low deck heights. Currents in Buttermilk Channel and the probability of debris in the channel during heavy weather must be considered. These piers are not recommended for visiting Navy ships during storms due to the nature and requirements of the Coast Guard's mission.

### 5.3.6 Passenger Ship Terminal

The Passenger Ship Terminal berths are highly recommended as storm berths. They are well protected from strong east-west winds, although somewhat exposed to direct north-south winds. The N-S winds may be intensified by channeling along the Hudson River. There is good depth alongside, but deck heights could be awash in severe storms due to storm surge. These berths are normally used for mooring cruise vessels during the season, and availability would be controlled by the City of New York.

### 5.3.7 Brooklyn - Port Authority Marine Terminal, Piers 1-12

Piers 1 through 12 are marginally recommended for storm mooring. Wind and wave protection are fair to good. The inside pier berth (i.e., in Atlantic Basin) at Pier 12 is the most protected berth. Outside berths facing Buttermilk Channel and the East River are subject to damage from floating debris. The Brooklyn side at the East River entrance, despite its appearance as being fairly well protected by lower Manhattan, was subject to heavy wind/wave battering by NW winds in the September 21, 1938 hurricane. These piers are controlled by the Port Authority.

### 5.3.8 Columbia Street Marine Terminal

The Columbia Street pier appears to be an excellent storm berth. Located on the east side of the Upper Bay in Gowanus Bay, the berths are easily accessible and have good protection from wave action. Wind protection is provided by surrounding structures and terrain. The piers are large and deep berthed, but at 10 ft above MLW, could be awash in severe storm surge. They are controlled by the Port Authority of New York/New Jersey.

### 5.3.9 Port Elizabeth and Port Newark

Ports Elizabeth and Newark are colocated in Newark Bay and are similar in size and function. Both are large, modern terminals handling primarily general and container cargo. The terminals are somewhat exposed to high winds due to the generally surrounding flat terrain (Newark Airport to the west and Newark Bay to the east); however, construction on the wharves offers some N-S wind

protection. Fetch across Newark Bay is limited, so wind/waves buildup is restricted. Although the berths should provide good storm berths, they are not recommended as primary choices due to heavy commercial traffic and the difficult access route to reach them. Port Elizabeth is controlled by the Port Authority of New York/New Jersey and Port Newark is controlled by the City of Newark.

#### 5.3.10 Howland Hook Container Terminal

Howland Hook on the northwest side of Staten Island at the northern terminus of Arthur Kill is a modern wharf. It is somewhat well protected except from a north to northwest wind. With only 7 ft of deck height above MLW, the wharf is subject to severe inundation during major storm surge; Hurricane Donna caused 11 ft surge in the area. The terminal handles heavy commercial traffic, has difficult access, and is not recommended for storm berthing.

#### 5.3.11 Former New York Naval Shipyard

Located 1.7 miles up the East River from Upper Bay in Wallabout Basin, these three piers are well protected from both wind and wave action. However, access to the piers may be a problem due to harbor congestion and the tricky currents in the East River (see Coast Pilot 2). Late arrival after winds and seas have picked up will increase navigation problems. These piers provide good storm berthing with possible inundation during heavy storm surge. The City of New York and the U.S. Navy own these piers.

#### 5.3.12 South Street Seaport Museum

The South Street Seaport Museum is not recommended for storm berthing. Pier 16 normally has three permanently moored vessels on exhibition and Pier 15 berths two barges. Strong East River currents, heavy local traffic congestion and the possibility of one of the permanently moored vessels or barges breaking moorings during heavy weather make this a questionable berth during a storm.

#### 5.3.13 Fort Schuyler

Fort Schuyler, at the extreme western end of Long Island Sound, is located on a slender, low, flat peninsula beneath the Throgs Neck Bridge. Although the pier deck height is 10 ft above MLW, heavy storm surge such as was recorded with the 21 September 1938 hurricane would place the piers approximately 5 ft underwater. This, plus exposure to winds from all quadrants, make the piers poor hurricane berths. They are not recommended.

#### 5.3.14 Use of Anchorages

Lower Bay is a large, exposed expanse of water. It is not recommended as an anchorage for any wind conditions above gale force. Gravesend Bay (Anchorage No. 25) with a sand bottom is considered a good anchorage with sufficient holding for most classes of naval ships up to gale force winds. Anchorage 44,

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off Perth Amboy at the western extremity of Raritan Bay and with 31 ft depth, could handle two ships of destroyer size, but is exposed to east winds. The northern part of anchorage 49F between the northern tip of Sandy Hook and the Earle piers provides good holding, but is reserved for ships with explosives. There are several other anchorages in Sandy Hook and Raritan Bay, but due to the exposed conditions and questionable holding they are not recommended.

Upper Bay contains deep-water anchorages off Bay Ridge (Anchorage No. 21A, B and C) and Stapleton (Anchorage No. 23A, B and 24). Bay Ridge Anchorages 21B and 21C are not good holding anchorages in strong west to northwest winds. 21A is a shallow-water anchorage used primarily for barges. Stapleton Anchorages are good, natural, deep-water anchorages with good wind protection provided by Staten Island to the west and good holding.

Anchorage No. 19 on the east side of the Hudson River between 80th and 137th Streets in Manhattan is well protected from east-west winds. Due to limited holding capability of the bottom, however, ships displacing more than 34,000 tons should not use this anchorage.

There are no general anchorage areas at the western end of Long Island Sound. General anchorage is afforded in the sound westward of Norwalk Islands toward the north shore with good holding in northern winds. There is anchorage for large vessels in the bight outside Bridgeport Harbor Light with some protection from northerly winds, but neither is recommended as hurricane anchorages.

### 5.4 RETURNING TO HARBOR

Returning to the harbor after successful evasion at sea can present many hazards if the storm struck the harbor area with any intensity. There is the possibility of wrecks in the navigation channels, large floating debris, damage to piers and general after-storm harbor congestion. Pier damage and/or storm surge may have disrupted alongside services. There is also the possibility that channel markers and other navigation aids may have shifted position or otherwise become unreliable.

5.5 ADVICE FOR SMALL CRAFT

Small craft should be removed from the water and tightly secured well above possible storm surge levels. Best protection is inside some type of storage building to prevent possible damage by flying objects or to prevent the possibility of broken tie-downs in high winds. Local knowledge is the best guide to weathering a storm in local harbors; the New York Harbor complex has many small harbors, coves, inlets, etc., which might provide protection in heavy weather. Look for good wind protection, and be aware of the local storm surge water heights in allowing enough mooring-line slack. Exceptional anchor weight should be used to prevent dragging in high winds; small craft that have broken their lines or are dragging anchor can pose a danger to other moored craft.



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XVII. PHILADELPHIA, PA

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## XVII. PHILADELPHIA, PENNSYLVANIA

### SUMMARY

This study concludes that the Philadelphia harbor is a haven from hurricanes. Philadelphia's distance from the open ocean via both the most direct overland route and along the Delaware Bay/River estuary provides protection for the harbor from both wind and storm surge extremes. Local flooding can occur, however, as a result of the combined effects of heavy precipitation and runoff, tidal action, and the piling up of water in the Delaware Bay/River under strong southerly winds.

It is recommended that U.S. Navy vessels, with the exception of those at the Navy Yard finger piers, remain at their regular berths and take prescribed measures to ensure protection of life and property. Ships at the finger piers that can be moved should be reberthed in the Reserve Basin.

There are no hurricane anchorages in the Delaware River, whose bottom is soft mud. However, anchorages in the lower Delaware Bay have been used by as many as 20-30 ships during a period of hurricane force winds.

### 1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

The port of Philadelphia is located on the Delaware River approximately 45 n mi above the Delaware Bay and 87 n mi from the Atlantic Ocean. Distances are measured along the 40 ft deep federal project channel, which extends from the ocean along the main channel in Delaware Bay and River to the Philadelphia Naval Shipyard at mile 81. The channel continues upriver to the Trenton Marine Terminal (mile 115), with a minimum depth of 25 ft.

The Delaware River flows into Delaware Bay at a point arbitrarily defined by the legislatures of Delaware and New Jersey as a line between Liston Point, Delaware, and Hope Creek, New Jersey (see Figure XVII-1). From the mouth of the river, Delaware Bay extends southeastward approximately 42 n mi to the Delaware Capes and the Atlantic Ocean. The Naval Base and the Philadelphia Naval Shipyard are at the junction of the Delaware and Schuylkill Rivers approximately 6 n mi southwest of the center point of the port of Philadelphia and 81 n mi (along the main channel) from the Atlantic Ocean. Figure XVII-2 shows the area of Philadelphia, the Delaware and Schuylkill Rivers and the Naval activities.

This hurricane haven evaluation was prepared by R. E. Englebretson and J. D. Jarrell of Science Applications, Inc. (SAI), Monterey, CA 93940.

# PHILADELPHIA, PA

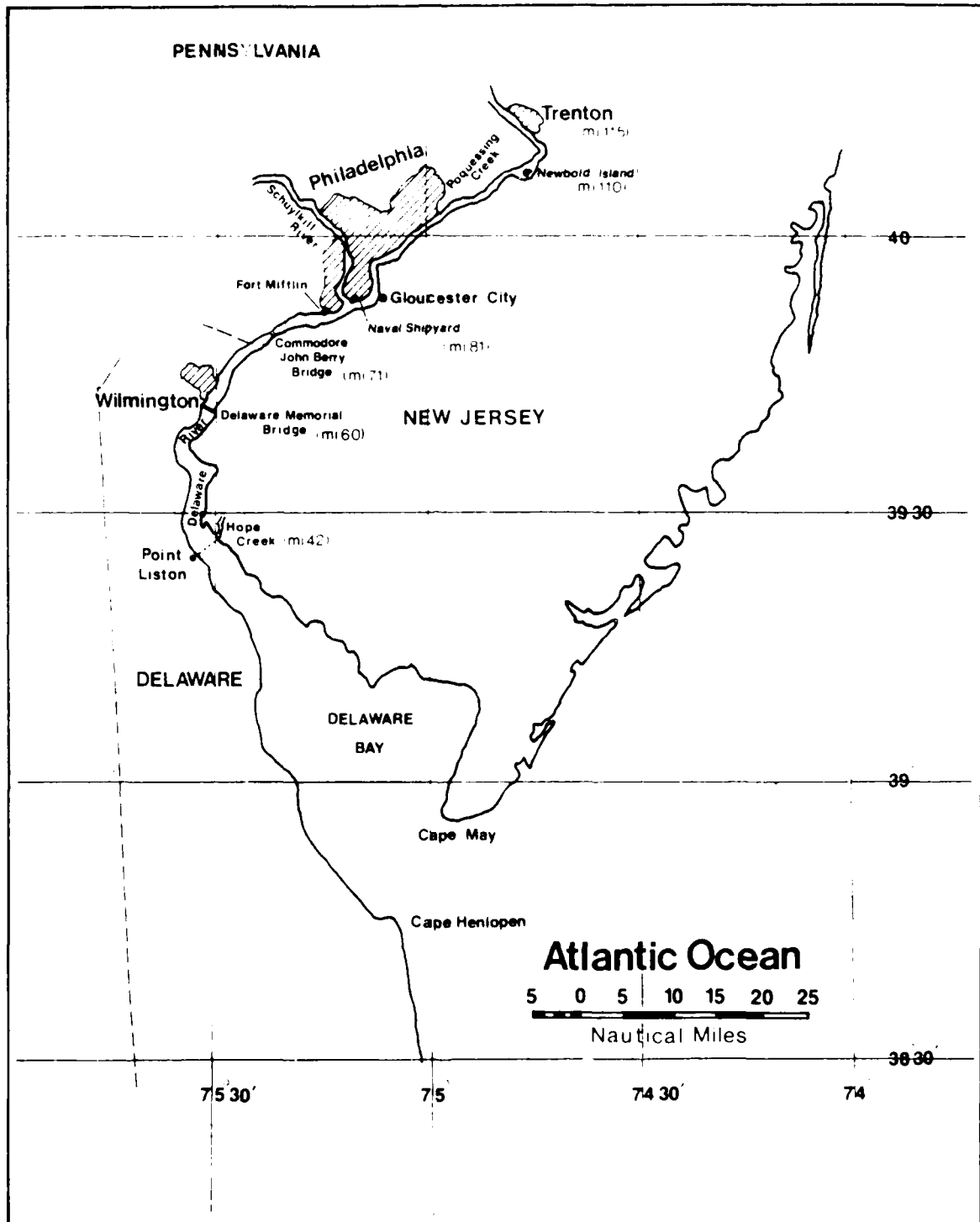


Figure XVII-1. Locations of Philadelphia, the Delaware River, and Delaware Bay.

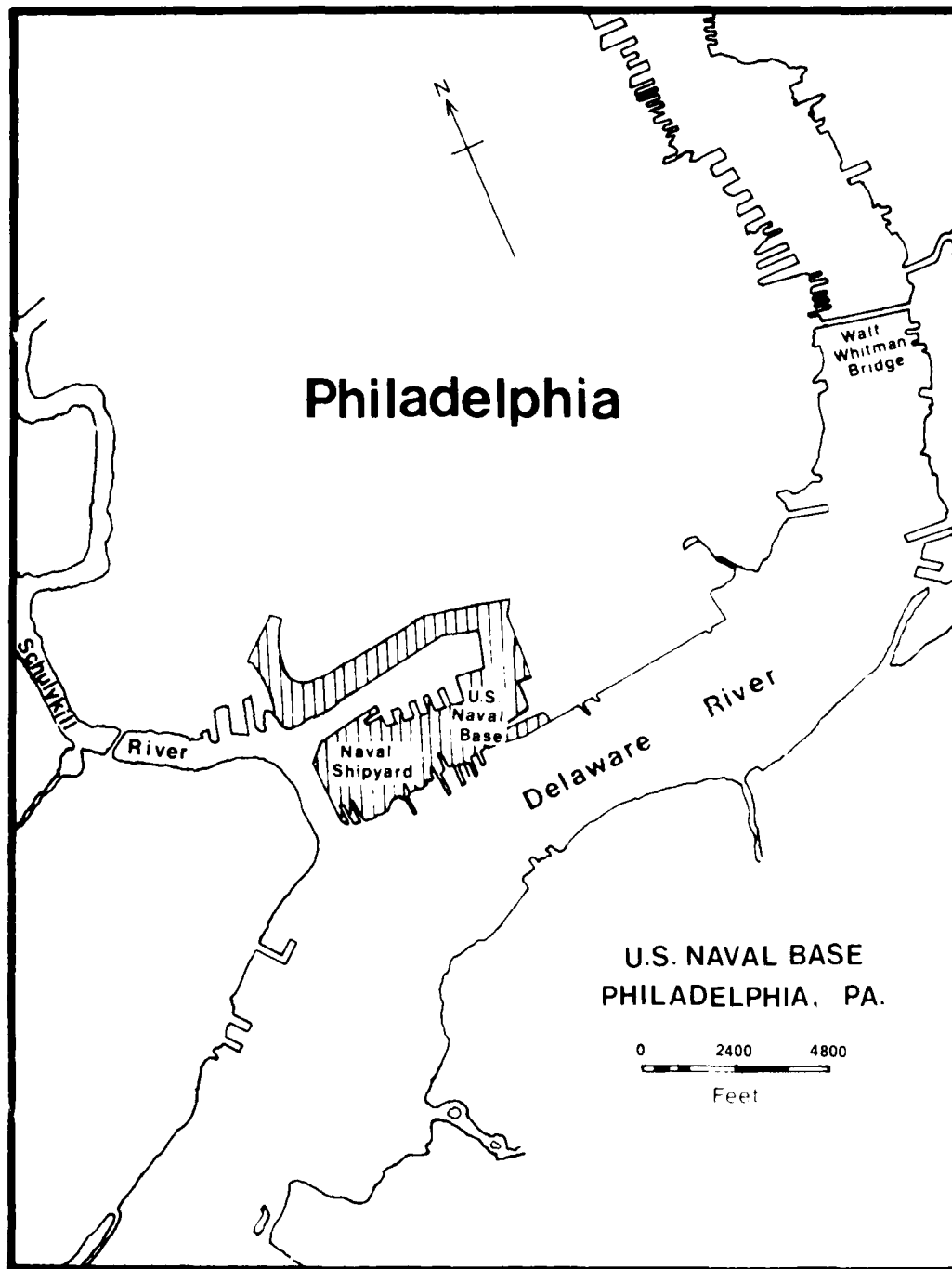


Figure XVII-2. The U.S. Naval Base/Naval Shipyard, Philadelphia, at the confluence of the Schuylkill and Delaware Rivers.

## PHILADELPHIA, PA

The entrance to Delaware Bay from the Atlantic Ocean is from the southwest. The entrance is about 10 n mi wide; Cape May, an extensive peninsula, is on the northeast side and Cape Henlopen is on the southwest side. Extensive shoals exist in the Bay entrance, particularly in the northern and central portions. The entrance channel for deep draft vessels is near Cape Henlopen. The topography of the surrounding land area is very flat with few points above 100 ft. The majority of New Jersey east of the Delaware Bay and River is less than 40 ft above MSL.

The Delaware River extends northward from the Delaware Bay and then northeastward to the Philadelphia area. In the immediate vicinity of the Philadelphia Naval Base, the river channel is oriented east-west.

The extensive shoaling of Delaware Bay greatly dampens any waves or storm surge generated by the open ocean. The distance inland to Philadelphia harbor, the natural barrier provided by the continental coastline, and the high latitude all combine to limit the threat of hurricane force winds reaching the harbor area.

Flooding is the major problem related to tropical cyclones in the Philadelphia area. The flat topography of the region gives little rise to the river bed, which produces a tidal range of nearly 6 ft in the Philadelphia harbor. Tidal action, storm surge and run-off during storms can combine to produce threatening flood levels.

The open ocean approaches to Delaware Bay have few obstructions (Chart 12214 Cape May to Fenwick Island).<sup>\*</sup> The 20 fathom curve is about 25 n mi offshore. Depths inside the 20 fathom curve are irregular, however, and deep-draft vessels should be sure of their position before approaching closer than depths of 12 fathoms.

Delaware Bay has many shoals as shallow as 6 ft (Chart 12304 Delaware Bay), and there are extensive shoal areas close to the main channel. The Bay has natural depths of 50 ft or more for about 5 n mi above the entrance, and then a federal project channel depth of 40 ft to beyond the naval facilities at Philadelphia. The naval facilities are located at the junction of the Schuylkill and Delaware Rivers (Chart 12313 Delaware River, Philadelphia and Camden). There are naval anchorages in Delaware Bay and the Delaware River as well as at the Philadelphia naval facilities. Details are given on the following charts:

- (1) Chart 12313 Delaware River, Philadelphia and Camden
- (2) Chart 12312 Delaware River, Wilmington to Philadelphia
- (3) Chart 12311 Delaware River, Smyrna River to Wilmington
- (4) Chart 12304 Delaware Bay
- (5) Chart 12214 Cape May to Fenwick Island

<sup>\*</sup> U.S. Coast Pilot 3.

## 2. HARBOR FACILITIES

Philadelphia is a major U.S. port comprising the navigable waters of the Delaware and Schuylkill Rivers. On the Delaware River the municipal limits extend from Fort Mifflin on the south to Poquessing Creek on the north, a distance of about 20 n mi. The port handles large quantities of general cargo in both foreign and domestic trade.

A federal project channel 40 ft deep is the main channel from the sea through Delaware Bay and River to the Philadelphia Naval Shipyard at Mile 81. The channel continues, with a minimum depth of 37 ft, up the Delaware River to the U.S. Steel basin opposite Newbold Island at Mile 110. Dredging depths to 25 ft continue upriver to the Trenton Marine Terminal at Mile 115.

There are two fixed bridges over the Delaware River below the Naval Shipyard. The Delaware Memorial Bridge at Mile 60 has twin suspension spans over the main channel with a clearance of 188 ft for the middle 800 ft. The Commodore John Barry Bridge at Mile 71 has a clearance of 181 ft for a 1600 ft width over the main channel.

Philadelphia has more than 45 deep-water piers and wharves along its Delaware and Schuylkill River waterfronts. Most of the Schuylkill River facilities are used to handle bulk petroleum products. The general cargo piers and wharves are mostly 3-8 n mi beyond the Naval Shipyard on the Delaware River.

The Coast Guard Captain of the Port Station is located at Gloucester, New Jersey; the Marine Inspection Office, Coast Guard, is in the Custom House, Philadelphia.

### 2.1 NAVAL FACILITIES

The major Naval activities in the Philadelphia area are Naval Base, Philadelphia, and the Philadelphia Naval Shipyard. The Commander, Naval Base Philadelphia (COMNAVBASEPHILA), has been designated SOPA (ADMIN), Philadelphia.

The Port Services Officer under the Commander, Philadelphia Naval Shipyard (COMPHILANAVSHIPYD), is responsible for ensuring that all appropriate port services are rendered to ships under naval control in the Philadelphia area; this includes assignment of berths and anchorages, and use of piers. Assignment of shipyard berthing is made by the Naval Shipyard Berthing Officer.

### 2.2 NAVAL BERTHS AND ANCHORAGES

Figure XVII-3 shows the piers and wharves of the Philadelphia Naval Shipyard. Table XVII-1 provides lengths and least depth alongside information.



# PHILADELPHIA, PA

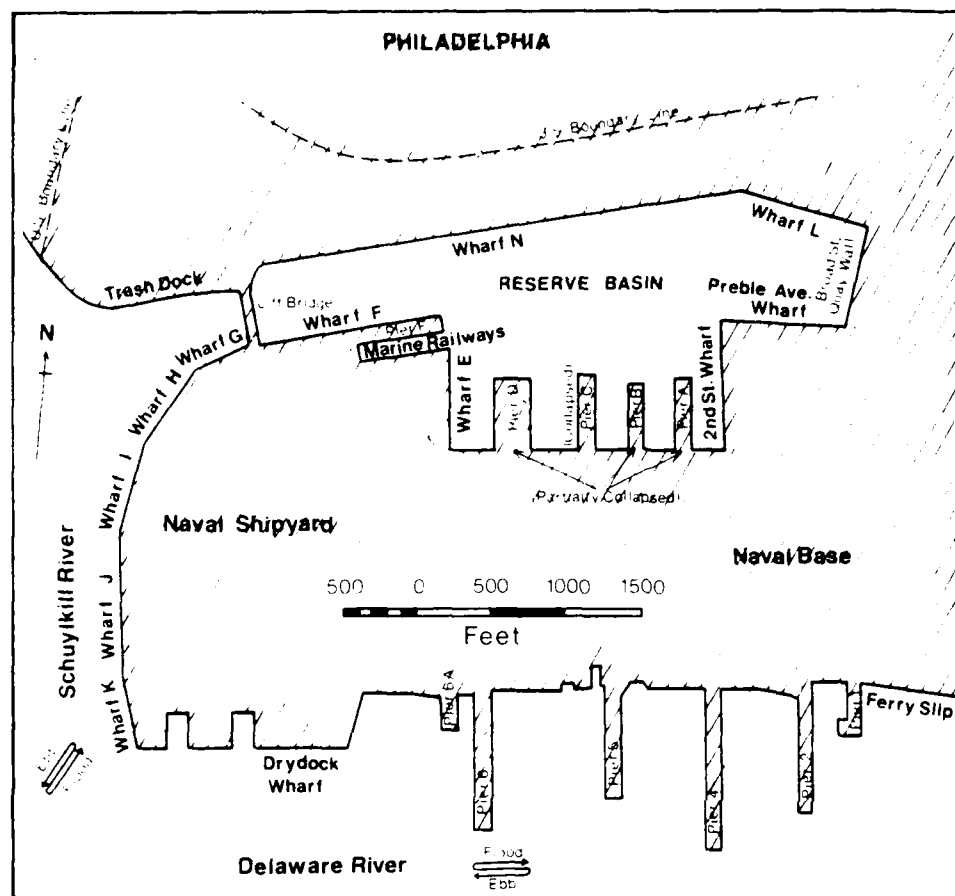


Figure XVII-3. Naval piers and wharves at the Naval Shipyard, Philadelphia.

Table XVII-1. Piers located at the Naval Base. E and W refer to east and west side of piers. Piers A through F are located within the Reserve Basin. See above figure for locations. Dredged depths are 30'-Piers 1, 4A, A, B, C, D, E, N (wharf), B8 and B9\*; 35'-Piers 2E, 5E, 6; 40'-Piers 2W, 4, 5W.

\*West of damage control center.

Pier	Length (Feet)	Least Depth Alongside (Ft at MLW)
1	390	E. 18.0 W. 18.0
2	894	E. 32.0 W. 30.0
4	1140	E. 33.0 W. 36.0
4A	390	25.0
5	778	E. 30.0 W. 30.0
6	970	E. 30.0 W. 30.0
6A	225	E. 22.0 W. 25.0
A	Collapsed	E. 21.0
B	Collapsed	E. 21.0 W. 21.0
C	Collapsed	E. 21.0 W. 21.0
D	Collapsed	E. 21.0
E	720	E. 19.0
F	600	25.0

## PHILADELPHIA, PA

Tidal conditions require that ships entering the Naval Shipyard for berthing arrive at assigned times. Destroyers or smaller ships are not restricted by tidal conditions in berthing at the shipyard. Berthing of naval auxiliaries and large-type ships is restricted to the following:

- (1) Piers 2E, 4E, 5E, and 6E: 1/2 hour after flood tide begins,
- (2) Piers 2W, 4W, and 5W: 1/2 hour after ebb tide begins, and
- (3) Pier 6W: berth only on slack or ebb tide.

Visiting Navy ships normally use Penn's Terminal which is about 6 miles above the Shipyard on the left bank. Those ships that cannot pass under the Walt Whitman Bridge (150 ft vertical clearance) use the Parker Avenue Terminal about 3 miles above the Shipyard. (Terminals are not shown in Figure XVII-3.)

### 2.3 TUG AVAILABILITY AND PILOTAGE

Tugs are available for all Navy ships of destroyer-escort size and larger, berthing at the Naval Base. Ships smaller than destroyer-escorts may request tug services at their option.

A large fleet of commercial tugs up to 2000 hp is available at Philadelphia. In general, however, most vessels make the run from the sea to Philadelphia under their own power.

Pilots are not compulsory for U.S. Navy ships, but are recommended, except in cases where the commanding officer is familiar with the river, current hazards, and instructions. Docking and Naval Shipyard pilots are available and should be used for all ship movements at the shipyard.

Pilotage on Delaware Bay and Delaware River is compulsory for all foreign vessels and U.S. vessels under register in the foreign trade. Pilotage is optional for U.S. vessels in the coastwise trade that have on board a pilot licensed by the Federal Government for their waters. Pilot services are available 24 hours a day. Pilots board incoming vessels from the pilot boat in the pilot cruising area off Cape Henlopen.

### 2.4 NORMAL TIDE AND WEATHER CONDITIONS

A factor of 4 hours 45 minutes standard time, or 5 hours, 45 minutes daylight saving time, applied to the slack water time at the entrance to Delaware Bay, gives the local time of the momentary slack water in the channel off the shipyard. Maximum current velocities averaging 2.2 kt can be experienced off the shipyard. The mean range of tide is 5.9 ft at Philadelphia.

The proximity of Delaware Bay moderates the Philadelphia area winter temperatures. Long periods of cold weather are rare, with below zero (Fahrenheit) readings occurring only every few years. Due to the maritime air, humidity is high in the summer and fog can be expected in fall and winter.

## PHILADELPHIA, PA

Prevailing wind directions are from the southwest in summer and from the northwest in winter. Destructive force winds are quite rare. The strongest summer winds occur mostly as gusts during thunderstorms. In winter the highest winds occur following the passage of cold fronts and/or low-pressure systems. Rarely have hurricanes caused widespread damage, then primarily through flooding. Flood stages in the Delaware River are caused by abnormally high tides due to the water "backing up" under the influence of strong south or southeast winds.

### 3. HEAVY WEATHER PLANS

Information regarding hurricanes and destructive storms is received by COMNAVBASPHILA and is relayed to SOPA who in turn will relay to all ships. Ships in the area, unless otherwise directed by competent authority, will ride out storms and disturbances at their regular berths.

Appropriate measures should be taken to protect life and property. Advance preparations should include:

- (1) All ships, if possible, make preparations for getting underway.
- (2) Put out additional mooring lines or wires and chains as necessary, and even up strain on all lines.
- (3) Set required material conditions and secure all loose gear, canvas, rigging, etc.
- (4) In the case of a local disaster, ships present at the Naval Shipyard will take actions in accordance with the Naval Base, Philadelphia Disaster Control Plan 3.

The National Weather Services VHF-FM radio stations provide mariners with continuous FM broadcasts of weather warnings, forecasts, radar reports and selected weather observations. VHF-FM radio stations with reception ranges of up to 40 miles that provide broadcasts for the Philadelphia-Delaware Bay area are KIH-28 Philadelphia, PA, 162.475 MHz; and KHB-38, Atlantic City, NJ, 162.40 MHz. Additional information on Coast Guard, commercial and National Weather Service weather broadcasts is in the Appendix of Coast Pilot 3 and in the NOAA publication "Worldwide Marine Weather Broadcasts."

#### 3.1 TUG AVAILABILITY

The Philadelphia Naval Shipyard has two 500 hp docking tugs available for use in the shipyard. The Navy contracts with commercial companies for all other tug support. There are 25 to 30 tugs up to a size of 2200 hp available in the port. While tug availability is adequate, it should be noted that there are no dedicated commercial tugs for Navy ships.

## PHILADELPHIA, PA

Arriving ships may confirm availability of tugs by contacting "Command Control," Philadelphia, on 2716 kHz or VHF channel 13 (156.65 MHz) or channel 23 (157.15 MHz) about one hour prior to arrival. Commercial tugs for towing or docking on the Delaware River are usually engaged at Wilmington or Philadelphia.

### 3.2 HURRICANE BERTHING

Berths in the Reserve Basin are the most protected sites within the Naval Shipyard and are considered suitable hurricane berths. The Shipyard finger piers and the dry docks along the north bank of the Delaware River are subject to flooding, and are not considered suitable as hurricane berths. Ship movement from these finger piers can close the river channel for one to two hours. Both terminals normally used by visiting Navy vessels, Penn and Parker Avenue, provide suitable berthing during high winds as long as proper procedures are followed.

In general, all substantial piers and wharves in the Philadelphia harbor are considered adequate for berthing during tropical cyclone passage as long as appropriate high wind/high water precautionary action is taken.

### 3.3 HURRICANE ANCHORAGES

There are no anchorages in the Philadelphia region of the Delaware River that have adequate holding for use in hurricane winds. It is not uncommon for merchant ships to drag anchor and run aground on the mud shoals during 50 kt winds in winter. The lower Delaware Bay however, offers anchorage areas suitable for use during high winds. Experienced pilots indicate they have on occasion observed 20 to 30 ships at anchor in the lower Bay during occurrence of hurricane force winds. (See chart 12304 for anchorage details.)

### 3.4 HURRICANE PLANS AND PREPARATION

The Commanding Officer of the Coast Guard Station, as Captain of the Port, is responsible for the safety of all vessels and waterfront facilities except Navy vessels and facilities. The NAVBASEPHILA Heavy Weather Instruction and PHILANAVSHIPYD Destructive Weather Plan provide direction and guidance for Navy units in the Port of Philadelphia during tropical cyclone events.

The Delaware River Ports' Council for Emergency Operations, formed in 1961, is a somewhat unique organization. It provides a structure under which the resources of state and local governments and the military commands of the area can be directed as a coordinated response to emergency situations. Continuing liaison among the various civilian and military activities is maintained. The Council's area of responsibility extends along the Delaware River from Trenton, NJ, to the Atlantic Ocean Capes of Delaware Bay. This organization will coordinate with Coast Guard and Navy responses during emergency situations.

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### 4. TROPICAL CYCLONES AFFECTING PHILADELPHIA.

#### 4.1 INTRODUCTION

Philadelphia, being north of the climatological zone of tropical cyclone activity and located more than 50 n mi from the open ocean, rarely experiences the full threat of hurricane damage. Geographically the station is just upriver from the inland end of a converging estuary (Delaware Bay). Flooding is the major concern due to the combined effects of run-off in the river and storm surge from the Delaware Bay.

The shape of the Eastern Seaboard provides to some degree a natural barrier for areas north of Hatteras against northeastward-moving, recurving tropical cyclones. Under certain synoptic patterns, however, tropical cyclones do not complete their recurvature and instead move rapidly northward. When such storms pass overland close to the west of Philadelphia, the port experiences the greatest threat of flooding.

#### 4.2 CLIMATOLOGY

For the purposes of this study, any tropical cyclone approaching within 180 n mi of Philadelphia is considered a threat. A tropical cyclone is classified as a hurricane if it was of hurricane intensity (winds  $\geq 64$  kt) at any time during its passage within 180 n mi of the port of study. It is recognized that a few tropical cyclones that did not approach within 180 n mi may have affected Philadelphia in some way, so to some extent this criterion is arbitrary.

The tropical cyclone season for the U.S. East Coast extends from May to November. Although tropical cyclones have occurred in the North Atlantic during all months of the year, all but two tropical cyclones that threatened Philadelphia occurred from June through November. One tropical cyclone occurred in each of the months of February and December. Figure XVII-4 is a monthly summary of tropical cyclone occurrences for the Philadelphia area. Of the 76 tropical cyclone threats that occurred in the 94-year period of record 1886-1979, 63 (83%) occurred in the months of August through October with the peak threat in August and September. Tropical cyclones that were of hurricane intensity at any time during passage within 180 n mi of Philadelphia also show a marked peak occurrence during August and September with 26 out of 36 (72%) occurring during those months.

Figure XVII-5 displays the tropical cyclones as a function of the compass octant from which they approached Philadelphia; it is evident that the major threat is from the south and southwest. An average of 0.8 tropical cyclones per year (or 4 in 5 years) pass within 180 n mi of Philadelphia, while an average of 0.38 per year (or about 1 every third year) are of hurricane intensity at some point during their passage.

# PHILADELPHIA, PA

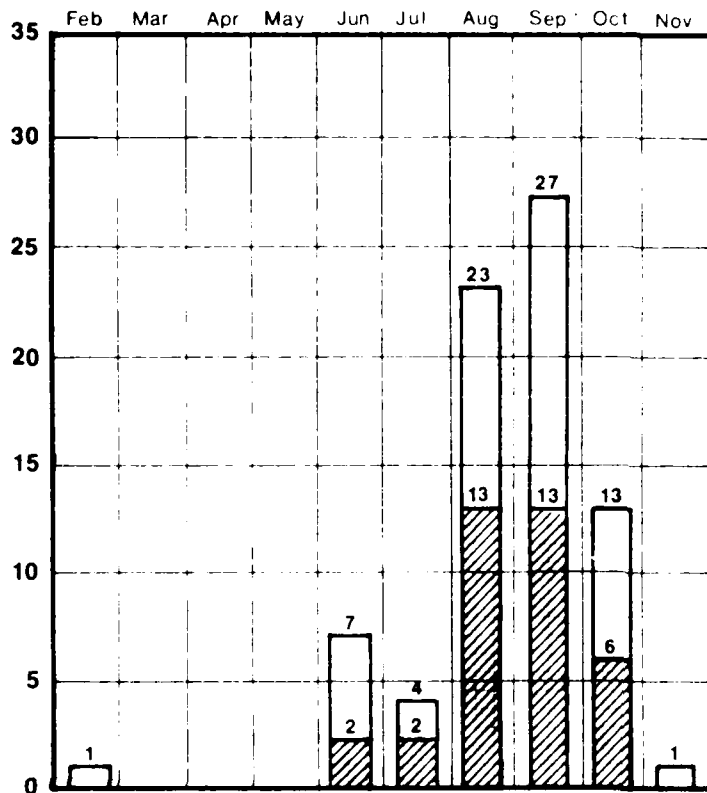


Figure XVII-4. Seasonal distribution of tropical cyclones passing within 180 n mi of Philadelphia, February-November (based on data from the period 1886-1979). Monthly totals shown above each column; numbers of threats of hurricane intensity are shown by hatched areas.

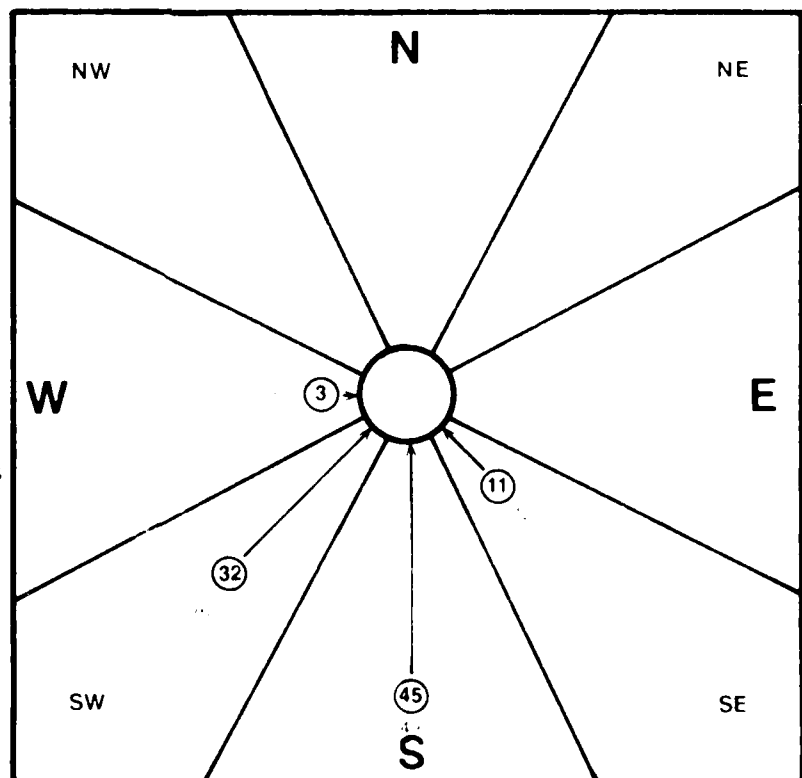


Figure XVII-5. Directions of approach of tropical cyclones that passed within 180 n mi of Philadelphia during the period 1871-1979. Numbers of storms approaching from each octant are circled; percent figures are percentages of total sample approaching from that octant.

## PHILADELPHIA, PA

Philadelphia (near 40°N) is located north of the typical recurvature latitudes (25-35°N) of most Atlantic tropical cyclones. The East Coast provides natural protection insofar as nearly all recurving storms approaching from the Atlantic either make landfall south of Hatteras or else pass the Philadelphia area offshore to the southeast.

Some storms occasionally do not complete the recurvature and are accelerated northward, a movement that typically occurs when an upper level trough is located over the eastern United States. Climatologically, this circulation pattern is more likely to develop during the fall season; therefore, the fast-northward-moving storm is most likely in the latter part of the hurricane season. September offers the greatest potential for such a storm to threaten the area because of three factors:

- (1) Tropical cyclone activity is greatest.
- (2) North Atlantic subtropical high pressure systems are strong.
- (3) An occasional deep mid-latitude trough is located over the East Coast during this fall transition period.

These factors can combine to modify the normal recurvature of a tropical cyclone and steer it rapidly northward into the Philadelphia area. Such fast-moving storms tend to lose less of their energy as they pass rapidly over the colder water between the north wall of the Gulf Stream, and the coastal areas. The interaction with the mid-latitude trough provides the atmospheric conditions suitable for conversion of the tropical cyclone to an extratropical storm. Under these conditions an intense, fast-moving, mid-latitude storm frequently develops.

When these storms pass over or just to the west of Philadelphia, the strong southerly wind flow over the Delaware Bay can create a storm surge. Storms of this type typically produce heavy rainfall, which further increases the water level at the head of estuaries such as Delaware Bay. The combination of storm surge and rainfall run-off creates extreme high water conditions for locations like Philadelphia.

Figures XVII-6 through XVII-9 are statistical summaries of threat probabilities based on tropical cyclone tracks for the 109-year period 1871-1979. The data are shown seasonally: the light lines representing percent threat for the 130 n mi circle surrounding Philadelphia, and the heavy lines represent approximate approach times to Philadelphia. In Figure XVII-9, for example, a tropical cyclone located near 25°N, 72°W in September has about a 20 percent chance of passing within 130 n mi of Philadelphia and, if the speed remains close to the climatological normal, it will reach the area in about 3 to 4 days.

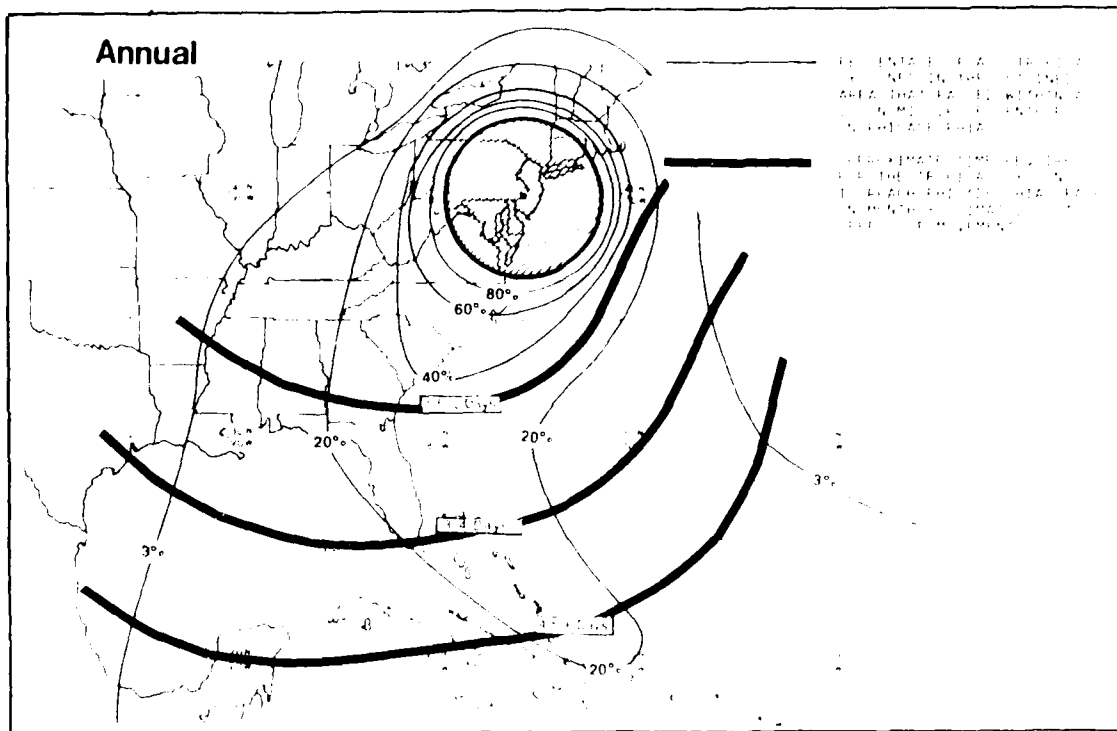


Figure XVII-6. Annual probability and CPA curves for all tropical cyclones passing within 180 n mi (shaded circle) of Philadelphia, based on data from 1871-1979.

Summarized annually (Figure XVII-6), the primary threat axis for Philadelphia is along the East Coast through Hatteras and off the east coast of Florida, then curving southeastward over the Bahamas. Most threat storms pass to the east of Philadelphia over the open ocean.

For late and early season storms, October through June (Figure XVII-7), the major threat axis is from the Gulf of Mexico then overland paralleling the Atlantic coast line. The source region for most of these threat storms is the western Caribbean and the Gulf of Mexico. Since 1886, there have been no November-June storms approaching within 180 n mi of Philadelphia while still maintaining hurricane force ( $\geq 64$  kt) winds.

During July and August (Figure XVII-8) the near threat is still overland from the southwest. The primary threat lobe extends from the Atlantic and a secondary threat lobe extends from the Gulf of Mexico. Most storms recurve over water, passing Philadelphia to the southeast. By September the threat axis of probability has shifted completely offshore (Figure XVII-9).

The times to CPA shown in figures XVII-6 through XVII-9 should be used with caution: it is not the average storm, but rather the exceptionally fast-moving storm, that poses the greatest danger to Philadelphia. Figure XVII-7, for example, indicates that an October storm located near  $25^{\circ}\text{N}$   $74^{\circ}\text{W}$  should reach Philadelphia in about 4 days. However, Hurricane Hazel of 14-15 October 1954 traveled this distance in about  $1\frac{1}{2}$  days.



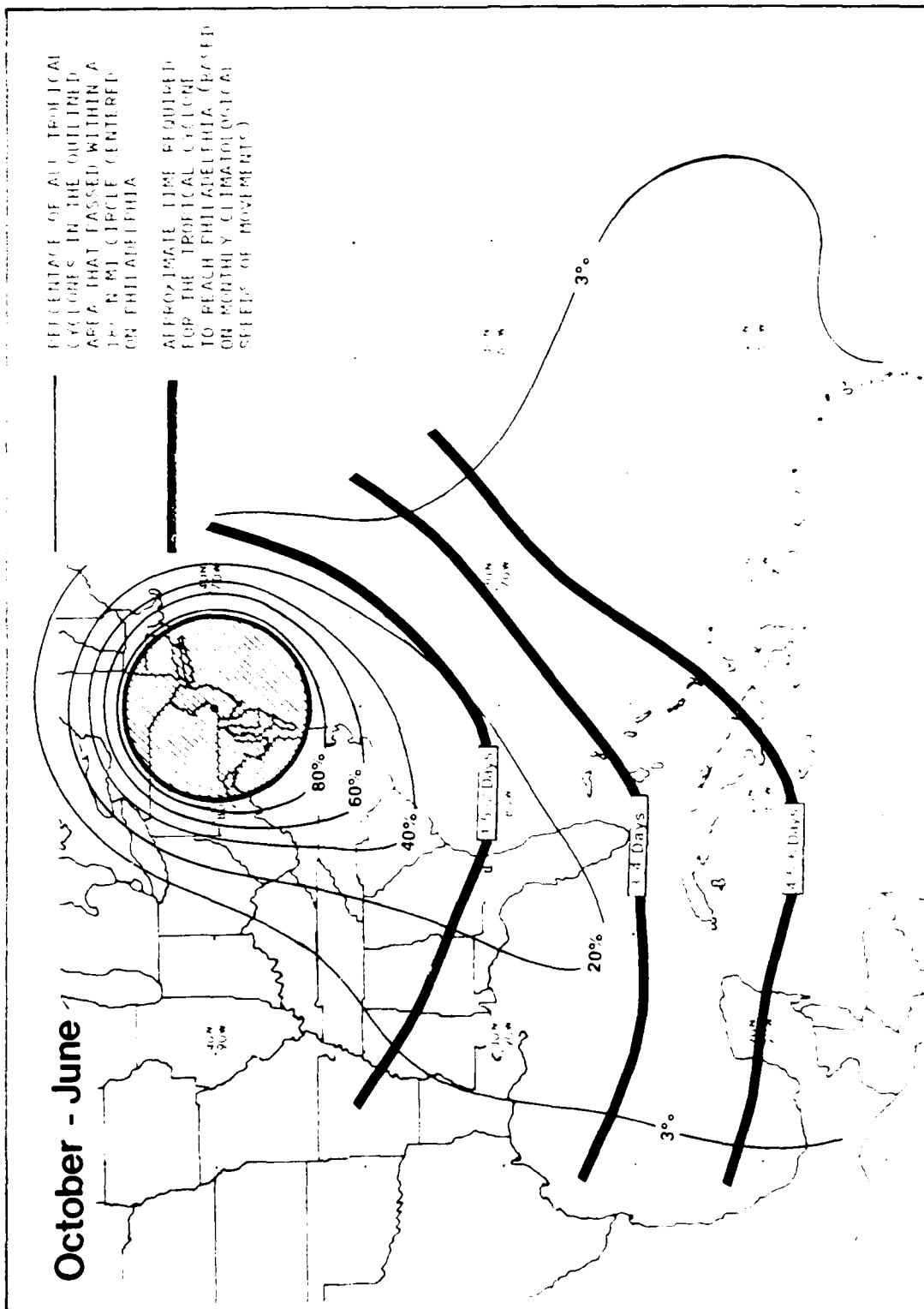


Figure XVII-7. Probability that a tropical cyclone will pass within 180 n mi of Philadelphia (shaded circle), and approximate time to reach closest point of approach, during October through June (based on data from 1871-1979).

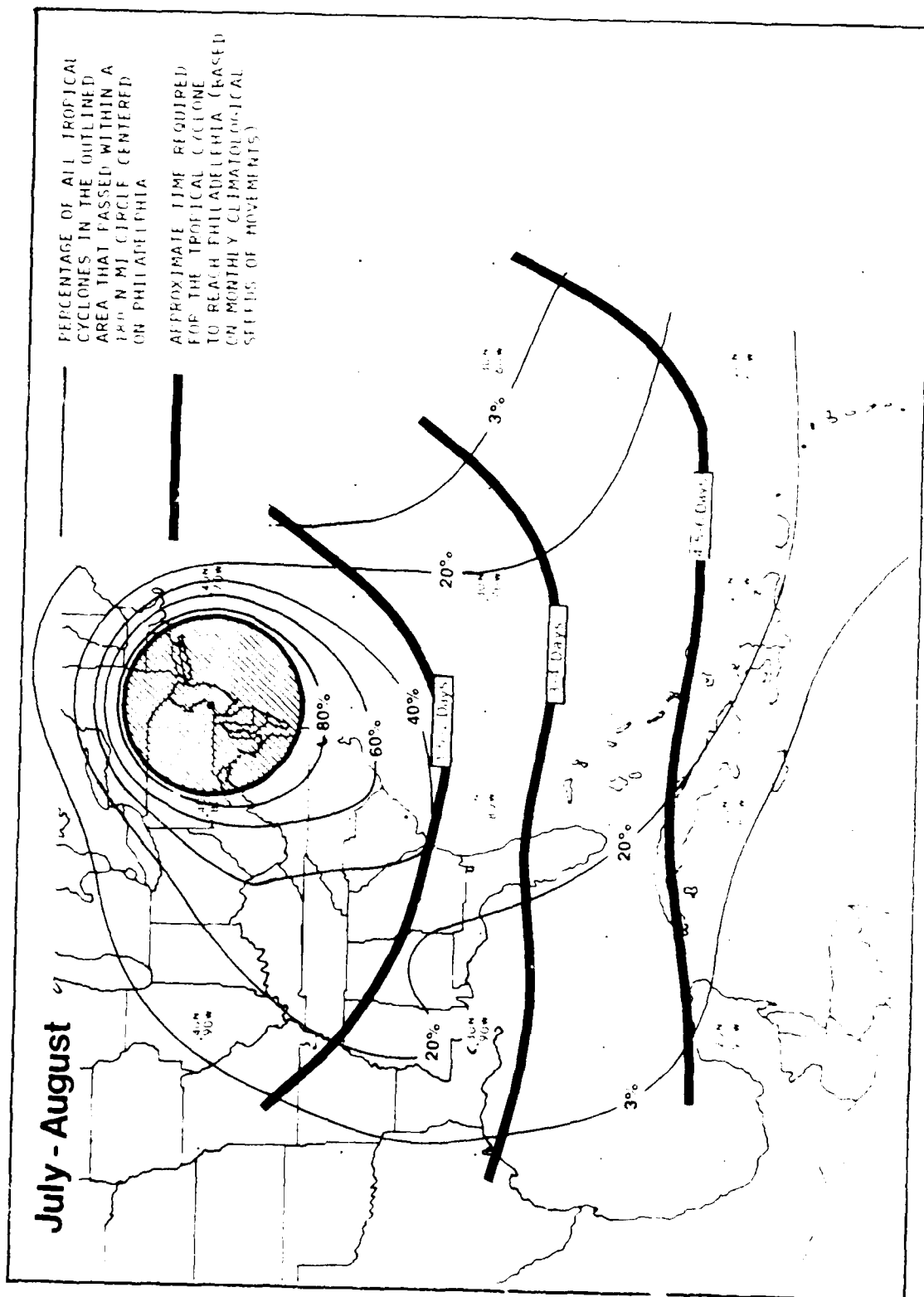


Figure XVII-8. Probability that a tropical cyclone will pass within 180 n mi of Philadelphia (shaded circle), and approximate time to reach closest point of approach, during July and August (based on data from 1871-1979).

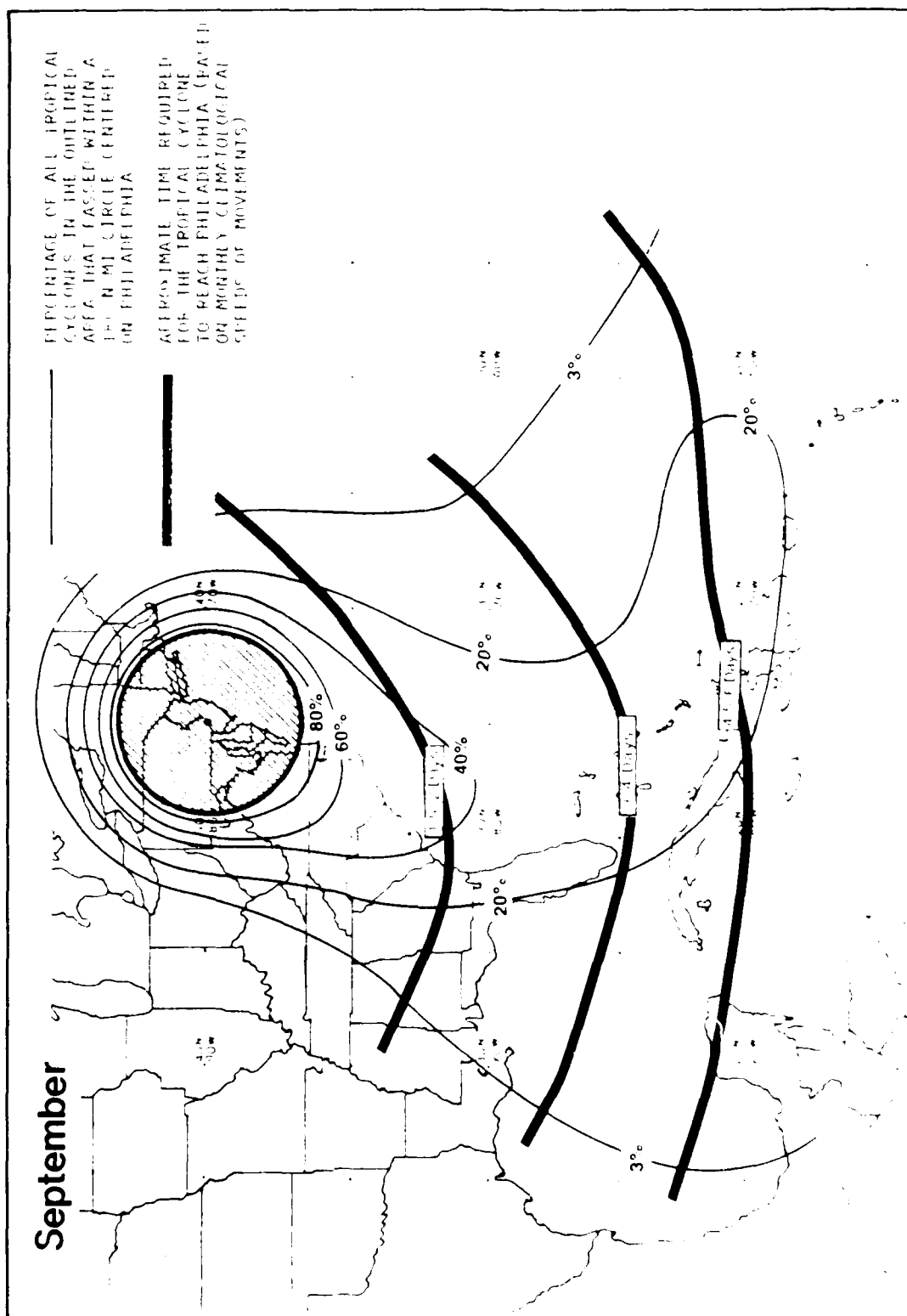


Figure 2411-9. Probability that a 'tropical cyclone will pass within 180 n mi of Philadelphia (boxed circle), and approximate time to reach closest point of approach, during September (based on data from 1871-1979).

## 4.3 WIND, WAVE AND TIDE EFFECT

Figure XVII-10 shows track segments of the 12 tropical cyclones out of 17 that passed within 140 nmi that produced winds greater than 22 kt at Philadelphia International Airport during the period 1941-64. The airport is located about 3 nmi below the Naval Airpy and on the north bank of the Delaware River. The beginning and end of each segment is the storm's position at the time sustained surface winds ( $\geq 22$  kt) were first and last recorded at the airport. The track of the one tropical cyclone that produced sustained winds of  $\geq 34$  kt at Philadelphia is also shown (IS Hazel, 1954).

The infrequency of strong winds at Philadelphia supports the port's designation as a hurricane haven, although this does not mean there is no threat of wind damage. During the passage of Hazel, for example, gusts of 60 mph or more were recorded at Philadelphia and with strong typically, gusts of 40 mph or more were recorded at the airport during the periods of sustained winds of 22-34 kt.

Furthermore, winds over open waterways, bays and the ocean are generally higher than those over adjacent land due to the reduced surface friction and turbulence. Wind speeds over Delaware Bay and open reaches of the Delaware River can be expected to exceed adjacent land wind speeds by approximately 50%. Significant wind waves can also be generated over the Bay. During Hurricane Doria of August 1971, the Coast Guard site at Swan Point, about 10 nmi west in the south central Delaware Bay reported northerly winds to 34 kt with wind waves 7-8 ft. The maximum center winds were 39-50 kt as the storm moved across the Delaware Bay.

Table XVII-2 lists 12 tropical cyclones between 1921 and 1964 that caused anomalous water level conditions at Philadelphia. The maximum surge of 2.4 ft occurred during Hurricane Hazel in October 1954. Hazel moved in a southerly northerly course, with a 42 kt speed of advance at time of peak surge, just west of Philadelphia. The significance of the storm center's passing to the west of Philadelphia clearly is supported by the data: storms passing to the west have an average center wind speed of less than 60 kt -- those to the east average more than 60 kt. However, the surge associated with storms passing to the west is significantly higher.

These findings are as expected. First, storms passing to the west are over land and in general have been over land longer than storms passing to the east. The loss of their low-level energy source (the ocean) and effects of friction over surface weaken their circulation. Second, the surge maximum occurs in the rear semicircle of the storm circulation, where Philadelphia will be in the rear of passages to the west.

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HURRICANE HAVENS HANDBOOK FOR THE NORTH ATLANTIC OCEAN  
CHANGE 1(U) NAVAL ENVIRONMENTAL PREDICTION RESEARCH  
FACILITY MONTEREY CA R J TURPIN ET AL. JUN 83  
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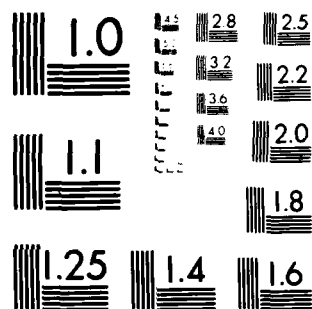
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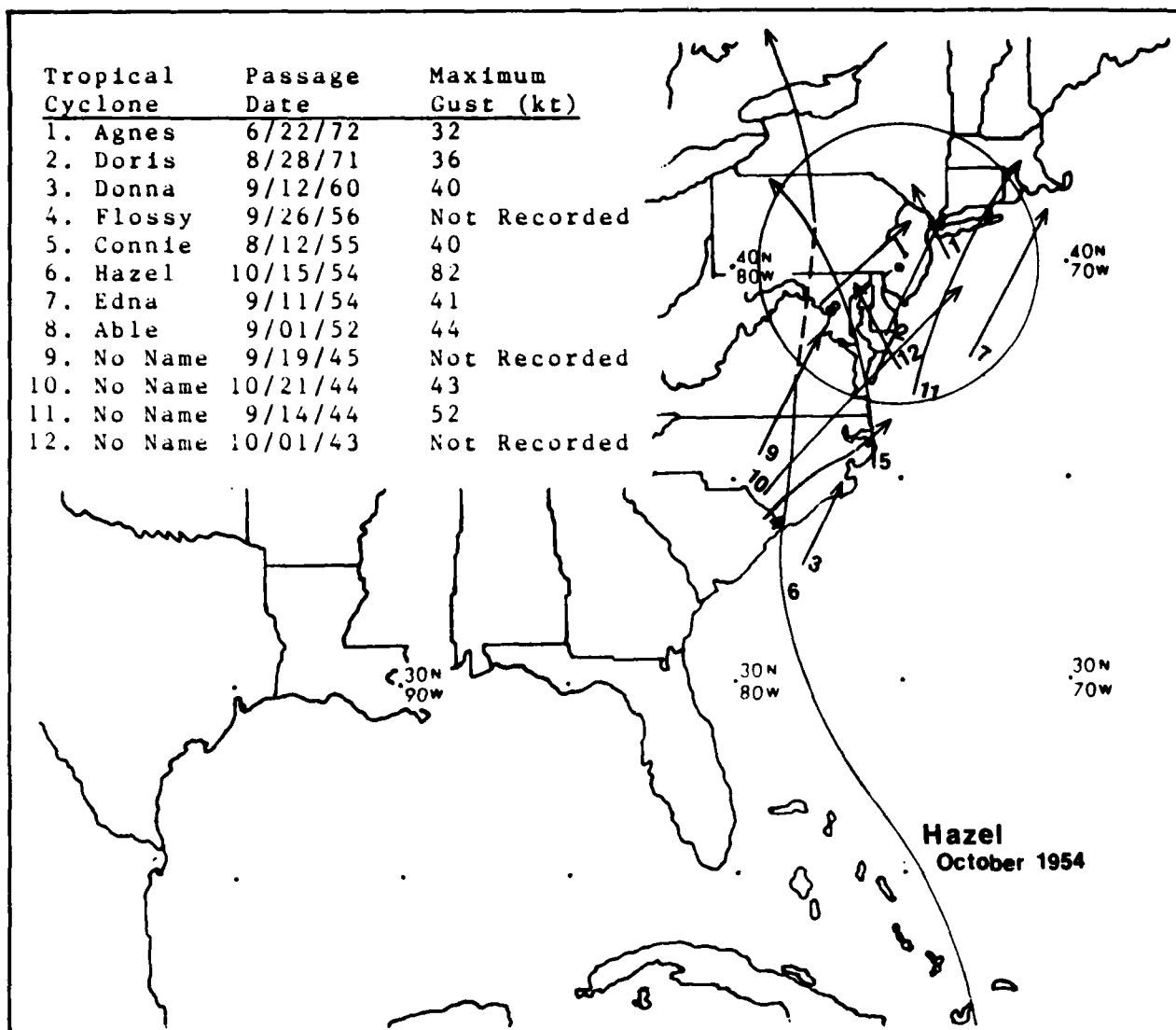


Figure XVII-10. Track segments of the 12 tropical cyclones that produced sustained winds greater than 22 kt at Philadelphia International Airport, 1943-79. Also shown is the track of Hurricane Hazel, October 1954, the only tropical cyclone on record to have produced hurricane force winds (gusts to 82 kt) at the Airport. The dashed portion of Hazel's track indicates occurrence in this area of sustained winds of greater than 33 kt.

# PHILADELPHIA, PA

Table XVII-2. Data on storms of tropical origin that caused anomalous water level conditions at Philadelphia during the period of 1928 to 1960. CPA is Closest Point of Approach and SOA is the tropical cyclone Speed of Advance at CPA. (After D. Lee Harris, 1963.)

Date/Name	CPA	SOA	Surge Height	Center Wind	Center Passed East/West
20 Sep 1928	129 n mi	17 kt	3.0 ft	40 kt	West
2 Oct 1929	45	19	4.5	35	West
23 Aug 1933	92	19	6.7	45	West
15-17 Sep 1933	141	8	2.3	70	East
18-19 Sep 1936	95	16	2.0	85	East
21-22 Sep 1938	115	38	2.9	85	East
14-15 Sep 1944	92	30	2.1	75	East
CAROL					
31 Aug 1954	107	31	2.6	85	East
EDNA					
11-12 Sep 1954	153	23	-1.5	90	East
HAZEL					
15-16 Oct 1954	120	42	9.4	70	West
CONNIE					
12-14 Aug 1955	69	14	5.0	45	West
DONNA					
12 SEP 1960	96	30	3.2	90	East

The exceptional storm tide effects at Philadelphia, however, are primarily due to local surge development in Delaware Bay and the retarding effect on river outflow by the strong southerly winds. The impact of these effects is further exaggerated by heavy rainfall runoff. The passage of a storm to the west of Philadelphia provides the southerly wind field over Delaware Bay that is necessary to create exceptionally high water at the port.

## 5. THE DECISION TO EVADE OR REMAIN IN PORT

### 5.1 REMAINING IN PORT PREFERRED

The port of Philadelphia is considered to be a hurricane haven, so remaining in port is the recommended action. The Penn and Parker terminals and the Reserve Basin provide suitable berthing during hurricane winds, provided prescribed measures to ensure protection of life and property are taken. Ships berthed at the Navy Yard finger piers that can be moved should be reberthed in the Reserve Basin.



## PHILADELPHIA, PA

The designation of Philadelphia as a hurricane haven is based on the following factors:

(1) Hurricane force winds associated with tropical cyclones are extremely rare in the Philadelphia area. The only occurrence during the 37-year period 1943-1979 was during Hurricane Hazel in 1954 when maximum peak gusts to 82 kt were recorded at the International Airport.

(2) The distance inland by direct route or along the Delaware Bay/River estuary greatly reduces the energy of the wind and hence its capacity to create water waves, as compared to the energy level in tropical cyclones when they first make landfall.

(3) Evading to the open ocean is a high risk action because:

(a) Under normal conditions it is a 5 to 5 1/2 hour passage from Philadelphia to the open Atlantic.

(b) The orientation of the coastline in the vicinity of the mouth of Delaware Bay allows only two alternatives once the open ocean is reached: head east and cross the likely track of the storm, or head northeast and try to outrun the storm. Neither is a preferred option.

(c) The 24- and 48-hour mean forecast tropical cyclone position errors are large, approximately 120 and 360 n mi (see General Guidance, Figures I-3 and I-4). Thus decision making becomes even more difficult once the open ocean is reached.

### 5.2 RUNNING FOR SHELTER

Ships at sea should give due consideration to their distance from the open ocean and the space restrictions of Philadelphia's river-type port before considering running to the Port of Philadelphia for shelter. However, the lower Delaware Bay provides more direct access from the open ocean and some shelter from high winds and seas. The Lower Bay historically has been used as an anchorage area during occurrences of hurricane force winds.

### 5.3 ADVICE FOR SMALL CRAFT

The universal advice for preparing small craft for hurricane force winds is to remove them from the water or bottom moor them. The next best action is to move them into the smallest bays or tributaries possible and allow for extreme tidal and flooding conditions. During the passage of Hurricane Connie in August 1955, the high water level exceeded the normal high tide level by about 4 ft. Table XVII-2 shows that a storm surge of 5 ft occurred with the passage of Connie; this storm surge apparently occurred near the time of high tide, resulting in the high water level. There are no recommended small craft mooring facilities in the main harbor of Philadelphia (Delaware River channel).

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